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With which is incorporated The Institution of Aeronautical Engineer

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

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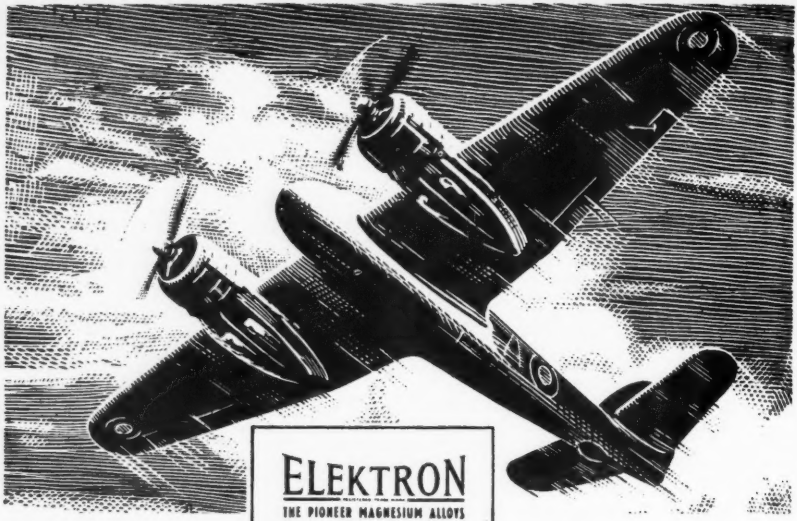

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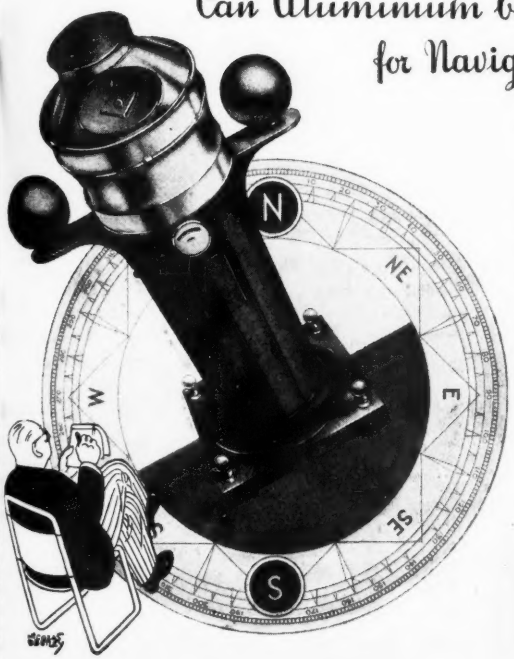

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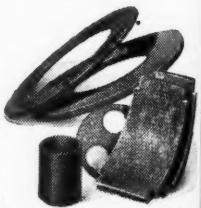

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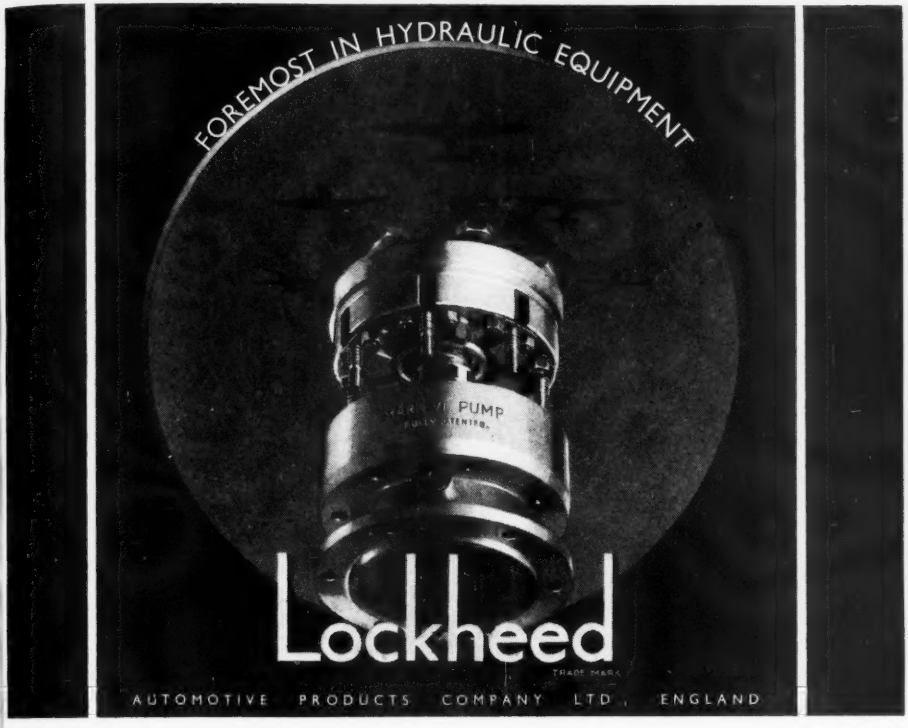

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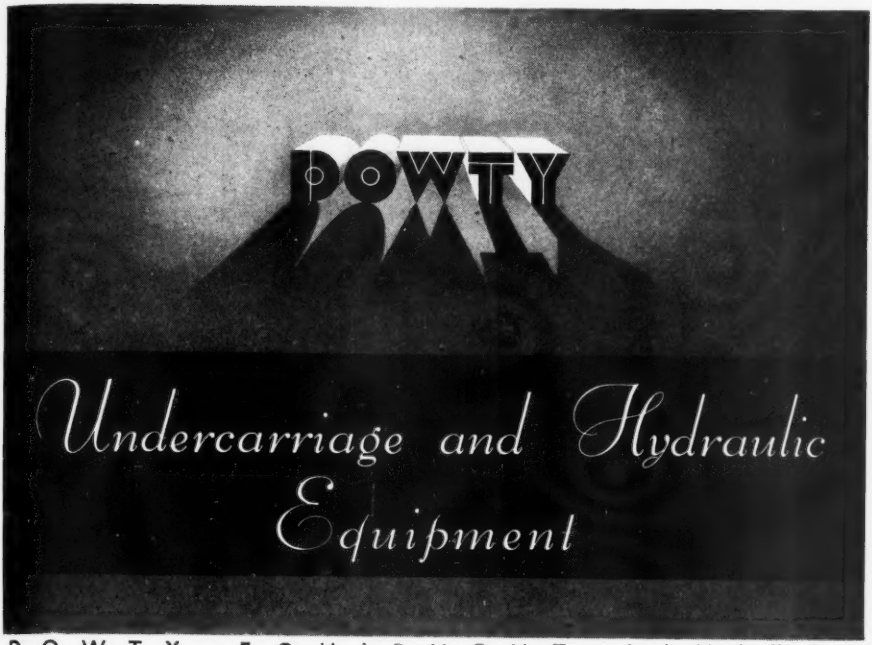

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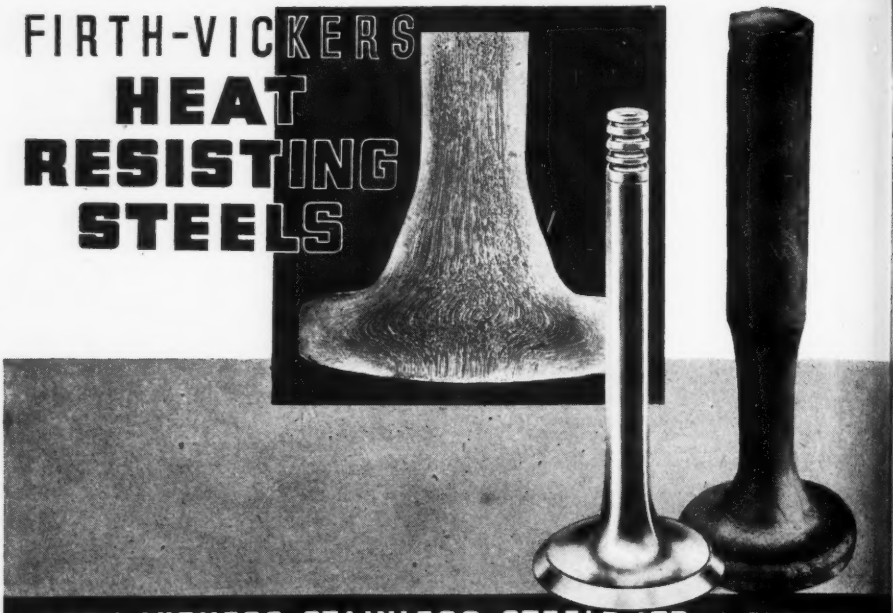

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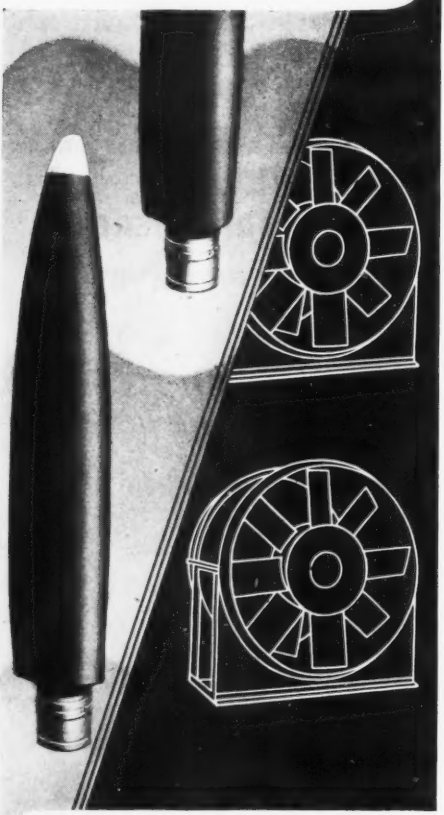

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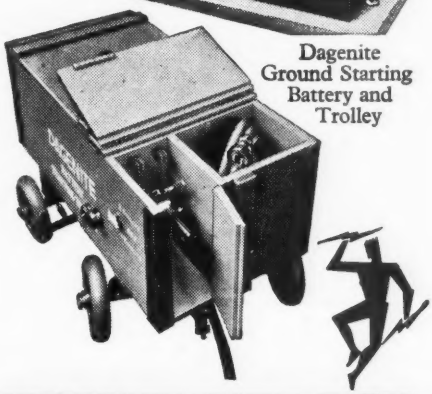

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THE JOURNAL
OF
THE ROYAL AERONAUTICAL SOCIETY

With which is Incorporated The Institution of Aeronautical Engineers.

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless such is definitely stated to be the case.

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All communications for publication in the Journal, or on general matters affecting the Society should be addressed to—

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PRINCIPAL MAY CONTENTS :

Vibrations in Aircraft IV (Concluded). R. G. Manley.
Determining Intermittent Ratings. H. Rissik.
Airscrew Stress Coefficients. T. H. Day.
Wing Lift Distribution. W. L. Morse.
The Russian Dive-Bomber P.E.2.
Practical Application of Stress Strain. F. C. Hoffman.

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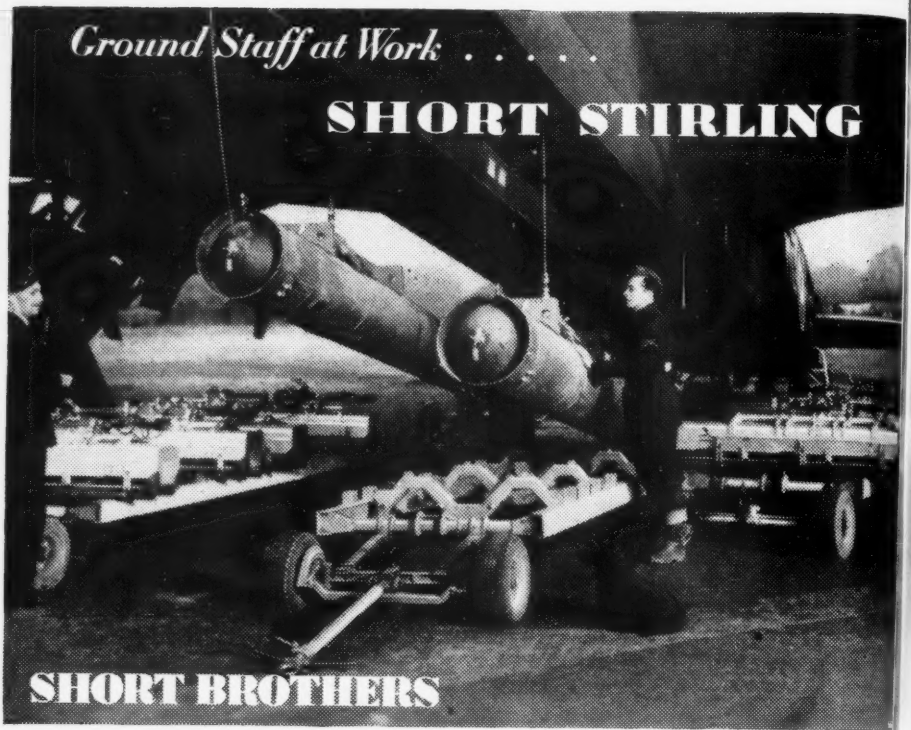
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MONTHLY NOTICES

MAY, 1944.

Wilbur Wright Memorial Lecture, 1944.

The 32nd Wilbur Wright Memorial Lecture will be read on Thursday, May 25th, 1944, at 6.30 p.m., by Sir A. H. Roy Fedden, M.B.E., F.R.Ae.S., on "Power Plants—Past and Future." The Lecture will be held at the Institution of Mechanical Engineers, Storey's Gate, St. James's, S.W.1 (by kind permission of the Council of the Institution). Light refreshments will be served before the meeting.

Graduates' and Students' Lectures.

The following lectures have been arranged by the Graduates' and Students' Section. They will be held in the Library of the Society at 7.30 p.m.:—

Thursday, May 11th, 1944.—"Power Plant Installation and Design," by Mr. J. A. Churchill.

Thursday, June 1st, 1944.—"Possible Developments in Air-Cooled Engines," by Mr. B. G. Markham, M.A., A.F.R.Ae.S.

Branch Lecture.

The following lecture has been arranged by the Luton Branch of the Society, on Wednesday, May 3rd, 1944, at 7.15 p.m.:—

"Debunking Aeronautical Science," by Mr. C. G. Grey.

Election of Members.

The following members have recently been elected:—

Associate Fellows.—Alastair Anthony John Edgar Boast (from Graduate), Henry Edward Merritt, David Ronald Newman (from Graduate), William John Scull, Peter Shaw (from Graduate), Harry Udall (from Graduate), Daniel Norman Walker.

Associates.—Harry William Boyett, John Collenette Evans, Lionel Richard Hay, Yehuda Holbitz (from Graduate), Alan Johnstone, William Johnstone McMeekan, Robert Maxwell McRobb, Alfred Henry Matthews, John Nithsdale, Leo James Riordan, Frank Trewhitt Smith, Rex Webber.

Graduates.—Eric Nigel Atkey (from Student), Dennis Herbert Bonfield, Michael Gordon Kidston Byrne (from Student), Geoffrey Lawrence Fletcher (from Student), Robert Earl Hanley, Walter Dickens Hunter, Lionel Cecil James, Robert Elkan Landau (from Student), George Maurice Martin Magill (from Student), Denis Richard Maguire, Herbert Austin Mather, Frederick Reginald Murray, Douglas Gordon Robertson, Gilbert Frank Satchwell, John Vernon Sadler, David John Saunders, Thomas George Holmes Woolford.

Students.—Ronald Arthur Berridge, John Graham Bott, Vincent James Wakeman Cresswell, Michael Joseph Crofton-Sleigh, Geoffrey William York Heath, Murray Heifetz, John Magson, John Secord Marshall, Victor Charles Pickett, Raymond Sidney Pyart, George Gerrard Rimmer, Alec Ryden Walley, William Frederick Walker, Norman Leslie White, Alexander Wilson, Robert Wilkinson.

Companions.—Joseph Dubsky, James Colin Montgomery, William Trevor Trewartha.

An Introduction to Industrial Management.

The attention of members is called to a course of lectures and discussions on the subject of Industrial Management, organised by the University of London. The following are the particulars:—

Lecturer: T. G. Rose, M.I.Mech.E., F.I.A.A., M.I.P.E.

(late Chairman of the Council of the Institute of Industrial Administration).

Outline Syllabus of the Course.

Friday, May 5th.—II. Production; its main variations, and how they affect management methods.

Monday, May 8th.—III. Distribution. Principles and practice.

Friday, May 12th.—IV. Industrial accounts, and the presentation of working results.

Monday, May 22nd.—V. Personal problems; past, present, and future.

Friday, May 26th.—VI. Summary. The function of General Management.

In accordance with the University Extension method of work each lecture will be followed by a discussion period in which free discussion on any points of difficulty will be encouraged.

Fees: For the Course of Lectures, 5s. 0d.; Admission to Single Lectures, 1s. 6d.

Applications for tickets of admission to the Course should be addressed to the Accountant, University of London, the Senate House, Bloomsbury, W.C.1, and marked " Extension Lectures " on the cover.

Tickets may also be obtained at the Lecture Hall on the occasion of each lecture.

The lectures will be held at 5.30 p.m. at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

Additions to the Library.

Pamphlets in italics with location reference following in brackets.

Books marked * may not be taken out on loan.

A.a.301.—Aerodynamics. (2nd Ed.) N. A. V. Piercy. English Universities Press. 1944. 30/-.

*B.g.134.—Aircraft of the Fighting Powers. Vol. 1, 1940 Aircraft. Ed. by D. A. Russell. Aircraft (Technical) Publications, Ltd. (Reprint.) 1944.

*B.g.135.—The Recognition of Operational Aircraft. Capt. G. B. Ransford. Sir Isaac Pitman and Sons. 1944. 3/6.

C.c.62.—Three Papers on Balloon Ascents. (1933-1936.) Prof. A. Piccard and Capt. A. W. Stevens. (Extracts from National Geographic Magazine, U.S.A., bound together.)

D.b.203.—*The Future of Air Transport. Wm. A. M. Burden.* (*Article in "Atlantic Monthly,"* 1944.) (Y.6.a.36.)

EE.j.28.—*Rotol Universal Accessory Gearbox.* (*Booklet No. R.26.*) *Rotol, Ltd.* 1942. (PEE.3.c.8.)

EE.j.29.—*Rotol Auxiliary Generating Plant, P.6.* (*Booklet No. R.33.*) *Rotol, Ltd.* 1943. (Y.7.a.14.)

G.a.67.—*Corrosion of Boiler Tubes. T. Henry Turner.* (*Reprint of Lecture read before Inst. of Mechanical Engineers, Nov. 20,* 1942.) (Y.13.a.16.)

G.e.A.91 and 92.—Aluminium at War. W. C. Devereux. (Reprint from "Metallurgia," Feb., 1944.) Two copies. (PG.3.a.14 and 15.)

*I.c.20.—An Introduction to the Theory of Statistics. G. Udny Yule and M. G. Kendall. Chas. Griffin, Ltd. 1940. 24/-.

J.g.198.—*Smithsonian Miscellaneous Collections, Vol. 104, No. 3. A 27-day Period in Washington Precipitation. C. G. Abbot, Smithsonian Institution.* 1944. (Y.30.i.)

J.g.199, 200.—*Smithsonian Reprints* (1944):—

No. 3,710. Solar Radiation and the State of the Atmosphere. Harlan T. Stetson.

No. 3,711. The Sun and the Earth's Magnetic Field. J. A. Fleming.

(Y.30.ii.59 and 60.)

J.g.201.—Teach Yourself Meteorology. "Aeolus." English Universities Press. 1944. 3/-.

L.d.101.—*Civil Aircraft Navigators' Licences (Wartime). A.M. Pamphlet 44. (13th Ed.) Air Ministry.* 1944. (Y.15.iii.a.)

M.a.28.—Introductory Magnetism and Electricity. T. M. Yarwood. Macmillan and Co. 1944. 2/6.

Q.b.73.—Carnegie United Kingdom Trust: 30th Annual Report. 1943.

S.a.139.—The Flying Poilu. M. Nadaud. Hodder and Stoughton. 1918.

*UU.c.—*National Advisory Committee for Aeronautics: Technical Memoranda:*

No. 1,057. Researches on the Piston Ring. Keikiti Ebihara. (Inst. Phys. and Chem. Res., Tokyo, Vol. 10, No. 182, 1929.)

No. 1,058. The Theory of a Free Jet of a Compressible Gas. G. F. Abramovitch. (C.A.H.I. Trans. No. 377, 1939.)

No. 1,061. Analysis of Experimental Investigations of the Planing Process on the Surface of Water. W. Sottorf. (D.L.F.F. Jahrbuch, 1937.)

Income Tax.

In response to numerous inquiries with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes:—

"Ref. H.R.S. 34/C.I. 4420/63.

Dear Sir,—Further to your interview with Mr. Stonely at this office on the 19th July, I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(i) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business carried on; or

(ii) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,

(Signed) GEO. WILCOCK,

Principal Inspector of Taxes."

Advertisements.

The fact that goods made of raw materials in short supply owing to war conditions, are advertised in the Journal, should not be taken as an indication that they are necessarily available for export.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Institution of Mechanical Engineers (by permission of the Council of the Institution), at Storey's Gate, St. James's Park, Westminster, London, S.W.1, on Thursday, February 10th, 1944.

In the chair: Mr. A. Gouge (President of the Society).

The PRESIDENT said the occasion was an historic one, inasmuch as it was the first open meeting for the discussion of technical problems since the war, a fact which might be regarded as a sign of the times. Mr. E. T. Jones was the Chief Technical Officer, A. and A.E.E., Boscombe Down, and he did not think he needed any further introduction.

FLIGHT TESTING METHODS.

By E. T. JONES, M.Eng., A.F.R.Ae.S.

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1. INTRODUCTORY.

In common with other machines, each new type aircraft must be put through comprehensive and well-seasoned tests. Unlike other machines, however, the aircraft exists to fly and by so doing severs its contact with the earth. Even this would not present a peculiar test difference if the atmosphere were rigidly connected to the earth and had a constant pressure and constant temperature at all heights, for then the engine power would not change with height or place and the speed over the ground would equal the speed through the air. Likewise the rate of climb, the manœuvrability and the behaviour of the controls would be independent of height. In such an atmosphere, tests would be required at one height only and measurements such as speed, rate of climb, take-off and landing could all be obtained accurately and directly from ground apparatus.

The atmosphere is not so helpful, however; it moves with respect to the ground, it gets colder as we approach its summit and its pressure decreases to nothing. Furthermore, the pressure and temperature at a given tape-measure height vary from day to day and from place to place. Thus no direct measurements of the performance of an aircraft in still air can be obtained from ground apparatus and hence all the measuring apparatus must be carried in the aircraft. In addition, and because the engine power is dependent on air temperature and pressure, the aircraft must be tested throughout its height range.

The above two directives dictated by the atmosphere may be tiresome but they present no difficulty in the flight testing of aircraft. The major difficulties which exist are caused by the general and local air disturbances set up in the atmosphere by the passage of the aircraft itself.

For example, it is well known that a body moving through air (or liquid) sets up local pressure and velocity fields around it. The aircraft is no exception. This has two direct effects on flight test work. Firstly, the transmitting ends of all those instruments operated by static or dynamic pressure, such as the altimeter, air speed indicator, etc., must be situated outside this local pressure field, or alternatively, if within, corrections for this pressure field must be determined.

Secondly, the pressure contours within this field become steeper in gradient as they approach a part of the aircraft. Thus they change with the wing incidence, with the shape of external components and with the ratio of V/a, where V denotes the velocity of the aircraft and a the velocity of sound in air at the height considered. This ratio is called the Mach Number (M). When the speed of the aircraft is much less than the speed of sound the air ahead is warned of its approach and instead of being compressed against the leading edge of the wing and other components, it makes way for the passage of the aircraft. As the aircraft approaches the speed of sound the air ahead cannot be warned in time, and in consequence it does not make way. Instead, it is compressed and shock waves may be transmitted from parts of the aircraft as they meet the air, thus

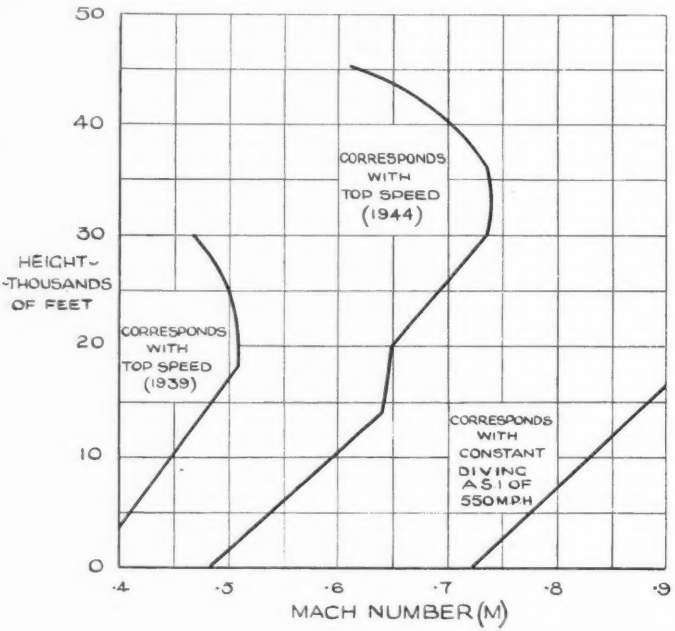


FIG 1

HEIGHT AGAINST MACH NUMBER

changing greatly the pressure distribution and hence the drag of the parts concerned. The centre of pressure of wings or tail may change as the Mach Number approaches unity, the balance of control surfaces may be upset and the loads on components may be increased. These features are aptly described as compressibility effects. They have to some extent controlled, and possibly limited, propellor design, but up to a short time ago the flight speed of the aircraft, and the local speed of the air over all external parts, were well below the velocity of sound and compressibility effects had not become important. Some recent fighter aircraft have exhibited symptoms of compressibility effects and in consequence recovery from dives on some new types has been difficult. It is noted that the velocity of sound reduces progressively with height so that such effects are most likely to be experienced at high altitude. Fig. 1 illustrates the approximate jump in Mach Number between 1939 and 1944.

So far I have introduced a background to flight test work in terms of the young pilot's eager enquiries, "What will she do? Has she any vices?" There is much more in the flight testing of aircraft, whether it be transport, fighter or bomber, than is conveyed by such enquiries. For example, passengers of the transport will be more concerned about their own comfort and peace of mind than whether the pilot is exhilarated or comfortable when flying it. Similarly, after successful combat over the sea, the pilot's joy might be short lived if his compass were badly affected by the changed magnetic field of the guns after firing. The complete tests on a fighter or bomber cover an immense field, and some are of a specialised nature, such as the testing in flight of guns, turrets, bombsights, automatic controls, bomb and pyrotechnic installations, facilities for navigation, compass deviations caused by electrical services and gun firing, and tests of various wireless and Radar equipment. Functioning and reliability tests of the engine installation, with its sundry accessories, including fuel system, are required, together with tests of all engineering appliances, such as hydraulics, electrics, heating and cooling systems, etc.

Before proceeding, therefore, it is obvious that limits will have to be imposed, though it may not be practical to observe these limits rigidly. It will also be necessary to list the tests before proceeding to the methods employed, and then to show how the results obtained are adjusted, firstly for inherent factors, and then corrected to the standard or tropical atmosphere.

I am going to this length of detail because I am conscious of the fact that a large number of very young technically minded people have entered the R.A.F., aircraft firms and Government establishments during the last four years, and that authoritative data on relevant subjects has been scanty on account of the war. Furthermore, aircraft flight testing is a job for young people which involves test pilots, engineers, technical observers and physicists equally.

2. Scope of Flight Tests Considered.

The scope will be limited to those flight tests required to establish:—

(1) The characteristics and safeness of the aircraft as a flying machine, and

(2) The data required by the operator to enable him (a) to determine the fuel required for a given range and hence deduce the disposable load so as to keep within the weight that can be lifted from the ground within a prescribed distance, and (b) to decide the time of the journey at any selected indicated speed. The complete performance picture of the aircraft will be required to supply such data. On the other hand I would like to make it clear that designers, engineers, and all those concerned with the technical development of aircraft require much more information than the above.

I will refer also to the desire we all have in test work to replace visual reading instruments by recording instruments, to make provision for recording data which has not previously been obtained and for shortening the test flying period. A word of warning is here justified. Recorded time histories of control movements and aircraft responses must only be used to augment, and to give the reasons for, the test pilot's assessments of controls, aircraft behaviour, etc.—they must not be used by the engineer to prove on paper that the test pilot's general assessment is wrong. In other words, pilots' opinions of the behaviour is based on the subconscious blending of many factors no instrument can yet copy. Until such an instrument is devised their opinion must be accepted as final.

3. List of Flight Tests Required to Establish Performance and Behaviour Within the Scope Considered:

Generally speaking, the tests required to establish the performance picture of all aircraft are the same, but the tests required to establish the flight behaviour

will differ between types. For example, the bomber is not required to manœuvre to the same extent as the fighter, but on the other hand it might have to be flown in many different conditions. Thus a bomber may be fitted with three or more turrets and the operation of any one of these may affect the steadiness of the aircraft just at the time the gunner requires a stable platform in order to sight his guns. It may happen that all turrets are being operated at the same time and any of these is liable to be stopped by enemy action in any position. Thus a bomber must be dived to its limiting speed for a very large number of conditions, depending on the armament and other equipment fitted.

The tests necessary to establish the characteristics within the above scope are classified in Table I below:—

TABLE I.

Complementary Tests. See Part I.	Performance and Allied Quantitative Tests. See Part II.	Flight Characteristics. See Part III.	Miscellaneous Tests. See Part IV.
Measurement of air temperature.	Take-off.	Take-off.	Cabin and gun heating.
Difference between atmospheric pressure and the pressure at the static head.	Measurement of speed.	Longitudinal, Lateral, Directional } trim	Cabin contamination.
	Max. speed-height, Cruising speed-height } curves		Noise.
			Structure.
	Minimum speed for continuous cruising.	Longitudinal, Lateral, Directional } stability	
	Partial (or Saw-tooth) Ceiling } climbs	Longitudinal, Lateral, Directional } control	
	Range.	Stability and control at the stall.	
	Cooling tests of engine installations.	Spinning.	
	Landing and approach.	Steadiness in controlled flight.	
		Behaviour with one or more engines cut.	
		Manœuvrability.	
		Dives.	
		The baulked landing.	
		Determination of acceptable c.g. limits.	

As indicated in the above table, the tests described will be divided into four parts, that is, complementary tests will be dealt with in Part I, and so on. Those tests in which the handling (as distinct from good piloting) has a direct influence on the performance, such as take-off and landing, will be dealt with in Part II only. The description of the methods now employed in each test will be followed, where applicable, with the developments in hand. In Part V of the paper the methods employed for the reduction of the quantitative data to a given atmosphere are considered. Part VI is devoted to a discussion on the value of recording instruments for the tests of prototype and first production aircraft.

PART I.

Complementary Tests.

4. Air Temperature.

An error of $\pm 10°C.$ in the air temperature will occasion ± 10 m.p.h. error in the speed of a modern Spitfire and $\pm 3{,}000$ ft. in the maximum cruising height of a fully-laden Stirling. Thus a high order of accuracy (say $\pm \frac{1}{2}°C.$) in its measurement is required.

No aircraft is supplied with a thermometer of the requisite accuracy, and, either a special test instrument must be fitted, or the air temperature must be measured from an outside source. Because of its importance, this item is dealt with in greater detail in Appendix I.

4.1 *Present method of measurement.* At the A. & A.E.E. two Spitfires equipped with two different kinds of thermometer are used. Two flights to the ceiling are made daily and the air temperatures obtained are plotted against time with height as a parameter. These curves, supported by temperature traverses from Radio Sonde balloon ascents, are used for the interpolation of air temperature for all tests made. Some firms rely solely on the temperatures given by the Meteorological Office from Radio Sonde measurements, but these have a limited application because

(*a*) Their accuracy at high altitude may not be adequate, and

(*b*) They are obtained at a few locations only and the balloon, travelling with the wind, may cover many miles during its ascent.

4.2 *Developments* (*see also Appendix I*). Though the use of the above Spitfires ensures consistency between tests made on different aircraft, the method does not give the requisite accuracy during those periods in which large temperature changes occur. In consequence much experimental work has been done at the A. & A.E.E. to evolve a suitable thermometer. Such a thermometer, which will measure to $\pm \frac{1}{4}°C.$, has been designed and made recently at the A. & A.E.E. by Mr. Brewer, of the Meteorological Office. A batch of these instruments is now being made so that each aircraft under test can carry its own thermometer.

5. Measurement of Atmospheric Pressure.

The altimeter and the airspeed indicator both depend on being fed with the true static pressure at the height at which the aircraft is flying. Due to the local pressure field set up by the aircraft, the pressure fed to these instruments differs from the true static pressure. The magnitude of this difference varies with the wing incidence, the wing flap position and with the engine power. It may also depend on whether the bomb doors, or the like, are open or closed.

Throughout the normal speed range at ground level this difference of pressure can be measured accurately and simply as the difference in reading between two sensitive pressure measuring instruments (aneroids). One instrument is connected to the static pressure pipe line in the aircraft and the other is used to measure the undisturbed atmospheric pressure. The aircraft under test is flown in level flight throughout the practical speed range past a tower, or the like, sufficiently high (about 50 ft.) to ensure a negligible ground interference on the pressure at the static pressure head. The altimeter in the aircraft is photographed automatically at regular intervals during the run and the second aneroid is read by an observer on the tower who also gauges the height of the aircraft. Compressibility effects at the static pressure head, if any, are included in the measured pressure difference, but it should be noted that they may change with Mach Number which increases with altitude.

This measurement forms the basis also of the well known Position Error (Installation Error in U.S.A.) of the Air Speed Indicator system, which will be dealt with in greater detail under speed measurements in para. 7.

5.1 *Developments.* Specially sensitive open scale aneroids are required for these tests where medium speeds are being considered. At the ground level speed of fighter aircraft a reasonably accurate result can, however, be obtained from selected standard Kollsman instruments. The instruments used at the A. & A.E.E. are of special manufacture, 5″ diameter with a scale from −1,000 ft. to 5,000 ft. A batch of more sensitive instruments ranging from −1,000 ft. to 2,000 ft. are now being made.

PART II.

Performance and Allied Quantitative Measurements.

6. Take-off—Performance and Handling.

6.1 *Data required.*

(1) The distance of unstick (or roll).
(2) The distance to clear a screen height (50 ft.).
(3) Whether the manœuvre is straightforward.
(4) Repeat of (3) in various wind strengths along the wind direction and ±30° out of wind.

} In zero wind and using the optimum of auxiliary aids such as flaps.

(5) Whether there is too large a change of trim with undercarriage retraction to render the safety take-off technique " unsafe " and whether " sink " is reasonably small when the flaps are retracted.

(6) Whether the manœuvre is safe in the event of an engine cut.

(7) Should the pilot inadvertently start to take off with any control trimmer at its maximum deflection, has he the time and the strength to overcome its effect on the control until he has trimmed the control?

6.2 *Present methods of measurement* (*Appendix II and Figs. 2, 3 and 4*). For the quantitative measurements of (1) and (2) the pilot is instructed to use the technique which, in his opinion, will give the minimum distance to the screen consistent with the maintenance of the flight path after passing the screen. For

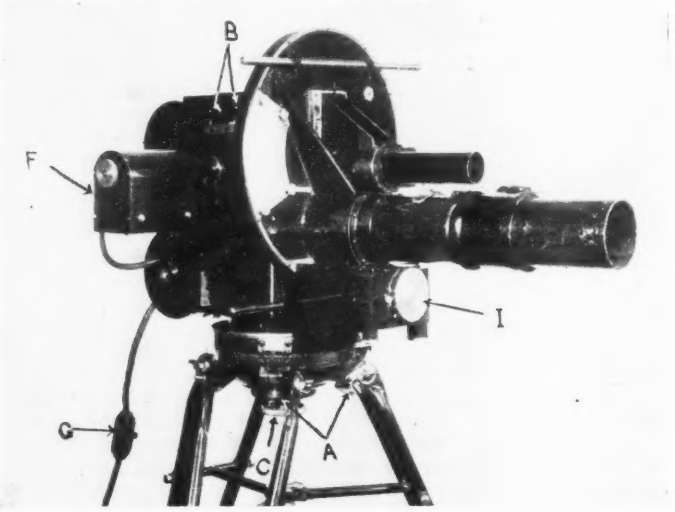


Fig. 2.
Take-off camera (F47).

F.A.A. types the minimum distance of roll is the criterion. Tests are made by three pilots in as light a wind as practicable.. All the data required to supplement (1) and (2) above, such as altitude, ground speed and flight path to, and beyond, the screen height can be obtained with a high degree of accuracy from the F.47

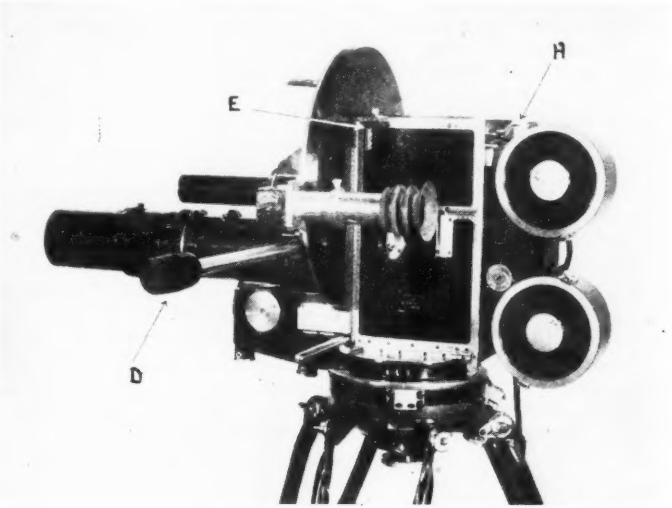


FIG. 3.
Take-off camera (F47).

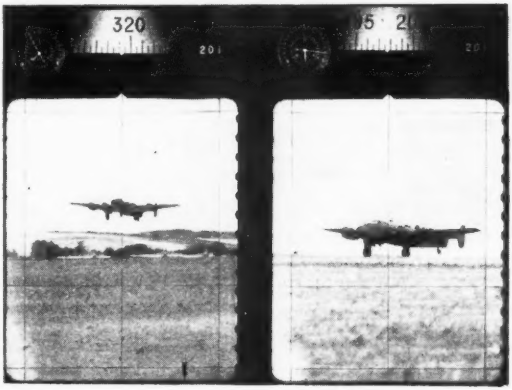


FIG. 4.
Examples of films from take-off camera (F47).

camera. This camera, designed at the A. & A.E.E. five years ago, is virtually a phototheodolite. It is illustrated in Figs. 2 and 3, while a facsimile of two of the frames is given in Fig. 4. The operation and design features are detailed in Appendix II.

The wind speed is measured at the time and place of take-off by a sensitive windmill or anemometer.

For information on 6.1 (3) and (5) we rely, excepting for special tests, on pilots' observations. Experience has shown that this is not entirely satisfactory, except on those aircraft in which the take-off is easy and straightforward. For example, no test pilot, however observant and experienced, can, to the nicety required, differentiate between an ineffective and/or heavy rudder and the tendency of an aircraft to swing. In other words, a mild tendency to swing may be described as violent if the rudder is very ineffective: and the change of longitudinal trim with undercarriage retraction may be stated to be too large, though it may well happen that the change of trim is small but that the elevator is both heavy and ineffective at low speed and full power.

Information on 6.1 (6) is obtained by simulating different phases of take-off at a safe altitude, followed by repeat tests on twins and four-engined aircraft immediately after the aircraft is airborne. (See also para. 23.12.)

Information on 6.1 (7) is also obtained at altitude and the tests made are described under trim in para. 17.0.

6.3. *Developments.* The F.47 camera is of adequate accuracy, though subsequent models should be provided with a vernier scale on the azimuth angular graduation. Like the N.A.C.A., however, we may find that two cameras are necessary to produce the accuracy required in take-offs made from runways and/or over greater distances than now obtain. Provision for increasing the film speed should be made on subsequent F.47 cameras in anticipation of accurate time correlation between two cameras used simultaneously.

The speed at unstick is of some importance, especially in F.A.A. types, in determining C_L at take-off. In consequence, an accurate knowledge of the wind speed at the time of unstick is required. We have two lines of development in hand for recording wind speed. First the revolutions of sensitive windmills at different heights will be recorded by veeder counters on the film of the take-off. Secondly, we are proposing to fit a swivelling pitot head to a very sensitive aneroid, the reading of which will be photographed during the take-off run. From this pressure record and the ground static pressure the air speed at take-off can be deduced. Provision should also be made for filming the A.S.I. so that the P.E. of the speed indicating system can be more accurately deduced.

To augment pilots' observations during take-off, the following additional instruments will be fitted on new types:—

(a) Rudder, aileron and elevator angles—Desyn Indicators.
(b) Rudder bar force—force deflection units with Desyn Indicators.
(c) Control column forces.
(d) Recording A.S.I.
(e) Longitudinal accelerometer on nose wheel types.

7. Speed Measurement (Excluding the Stall Region and Gliding Flight).

Since the first days of flight the measurement of speed has been tricky. To-day it is both tricky and difficult. In addition, the inherent errors due to compressibility are not yet completely determinable.

7.1. *Conventional pitot static system.* In this method the A.S.I. registers the differential pressure between the pitot and static pressure heads, on a speed scale. The process of converting its reading into speed requires the following steps:—

7.11 *Static pressure error at ground level.* At a low height we first determine the static pressure error caused by the static head being within the local pressure field of the aircraft. This is done within 50 ft. of ground level (at the A. & A.E.E.) and at this level the method (see para. 5) takes account of all errors in static pressure.

7.12 *Pitot-pressure error at ground level.* Since the calibration of the A.S.I. allows for the ground level compressibility effect on pitot pressure, there will be no error at ground level providing that the pitot head tube is along the air stream (actually up to $\pm 8°$ out of wind causes a negligible error) and that it is not positioned too close to the wing (or body) to which it is attached. Should the location of the head be such that the full pitot pressure might not be realised, it should be replaced by a swivelling pitot head fitted elsewhere.

7.13 *Position error of the A.S.I. system (or Installation Error) at ground level.* Since the static pressure only is in error, the pressure difference measured by the method of para. 5 can be converted directly to give ΔV_i at the observed A.S.I. of the test. This method (aneroid method) of determining the P.E. was first used (by the writer) on the Supermarine S.5 in 1931. It has given complete satisfaction since its inception at the A. & A.E.E. four years ago, and it is also used by many aircraft firms in Britain and the United States. Over 800 P.E. measurements have been made at the A. & A.E.E. in this way, and judging by the repeatability of the results it is more accurate than any previous method used. The accuracy of the P.E. measurement for given aneroids increases with speed. Fig. 5 shows that an error of 20 ft. in height (well within the overall errors) makes 1 m.p.h. error at 300 m.p.h. in the derived P.E.

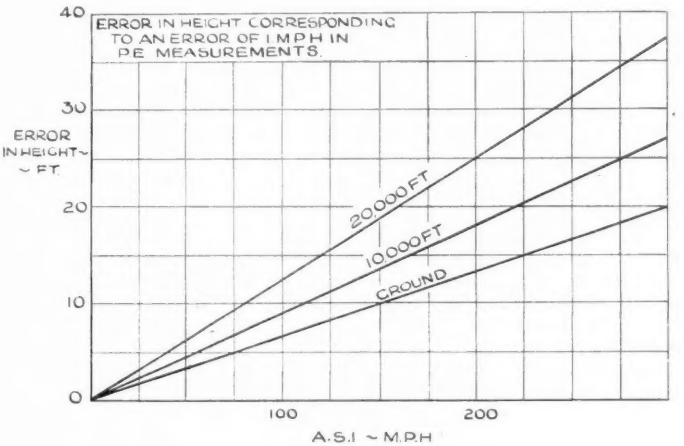


FIG 5

POSITION ERROR BY ANEROID

7.14 *Compressibility corrections at altitude.* There are two types of corrections for compressibility. First, the direct compressibility effects, and, secondly, the indirect effects caused by the strut supporting the pressure heads, and the wing, body or the like, to which the strut is attached.

7.141 *Direct effects.* These may conveniently be dealt with in three parts: (*a*) Ordinary pitot correction due to the fact that the A.S.I. calibration is based on

Differential pressure $= \rho_0 \ V_r^2 \ [1 + \frac{1}{4} V_r^2 / a_0]$, whereas the actual pitot pressure relative to true static is given by

$$\tfrac{1}{2} \ \rho_0 \ V_i^2 \ [1 + \tfrac{1}{4} V_i^2 / p a^2{}_0 + 1/40 (V_i^4 / p^2 a^4{}_0]$$

That is, the A.S.I. calibration allows for the ground level compressibility effect on pitot pressure, and a correction is needed for the residual difference between ground level and altitude.

(*b*) There may be a small static pressure error due to compressibility effects on wing lift. If, at given V_i we change M by changing the height, we change the wing incidence (because of the change in the slope of the lift curve) and, at a given incidence we change the pressure distribution round the wing. It may be noted that, when the static head is mounted on the wing we can calculate this effect from Glauert's law of the change of lift curve slope with M. The magnitude of this correction for static vents or static heads attached to the body is not known.

(*c*) There is a second modification to the normal compressibility chart if the P.E. is large. If there is a large P.E., V_i is changed at a given A.S.I. reading and a further compressibility correction is introduced.

7.142 *Indirect effects.*

(*a*) *"Strut correction."* As M approaches 0.5-0.6, the presence of the strut supporting the pressure head may cause the pressure to build at the static head. A small positive correction (may be as high as 2-3 m.p.h. on a modern fighter) has to be applied.

(*b*) *Wing shock wave.* R.A.E. tests on a modern fighter indicate that with certain wings a shock wave from the wing itself affects the P.E. severely in the dive at high values of M. On this aircraft the effect is apparent even at maximum level speed. Though some relief will be obtained on future aircraft fitted with high speed wing sections, the shock waves will re-appear at higher speeds.

7.2 *Other methods and developments.* It is noted that the corrections of speed enumerated in para. 7.14, though negligibly small on aircraft of medium performance, and small in level flight on modern fighters, large corrections in the dive at high M are possible. Despite the development of wing sections designed for high speed, these corrections will become greater as the top speed increases and new means of measuring the speed in test work may become necessary.

7.21 *Placing of transmitting ends of speed instruments away from the local pressure field.* As previously mentioned, there are compressibility effects on both pitot and static pressure heads and the magnitude of these effects is not known with precision. They can, of course, be reduced by ensuring that these heads are located well away from the wing or body, but in order to reduce the errors to a small value, very long supporting struts would be required. This is not practicable as a normal fitting since the drag of the aircraft may be unduly increased, nor is it practicable for test purposes because there is insufficient time to fit such struts and provide the necessary rigidity. However, some benefit in this respect will be derived from the decision to replace the normal underwing pitot static heads by a leading edge pole which will extend approximately 0.5c in front of the wing leading edge. For greater accuracy we may be driven in test work to using air logs or pitot static heads which can be lowered from, and trailed by the aircraft. Both of these instruments have been used extensively in the past for the accurate measurement of V and V_i respectively at low speeds in gliding flight where the measurement of P.E. is normally difficult. The application of these instruments to very high speed has not in the past been seriously considered but the R.A.E. intends to explore the possibilities.

7.22 *Use of a calibrated aircraft.* In order to ensure that any error in pitot pressure (as apart from compressibility errors) is automatically taken into account, Wright Field make their P.E. measurements by formating the aircraft under test with an aircraft fitted with a calibrated pitot static installation. Wright Field makes a success of this method, though our attempts

have not led to the requisite accuracy as defined by the consistency of a set of points and the repeatability of different sets of points. Also A. & A.E.E. have so many P.E. tests to make that this method would be uneconomical in aircraft and time.

7.23 *Ground speed by radio.* Some flight tests were made in the U.S. in 1940 to test the radio ground-speed system using standard radio equipment which showed that extreme frequency stability of the transmitters is not necessary. No complicated equipment with this system need be carried in the aircraft as the standard radio transmitter is usually adequate. This method will probably be developed after the war, but at present there would be too much interference to make the method reliable.

8. Speed Measurement at the Stall and in Gliding Flight.

8.1 *Stalling speed.* Theoretically the stalling speed of an aircraft is the speed associated with the maximum lift coefficient. The speed corresponding to C_L max. is seldom, however, attained, due to either lack of elevator control to bring the aircraft to the stall, or because the flow over some part of the supporting structure breaks down before this speed is reached. A reliable technique for determining the actual stalling speed and the definition of this speed are:—

From level flight at the best climbing speed the throttles are closed slowly and in unison with a gradual movement backwards of the control column. The pilot makes every effort to keep the aircraft level laterally by aileron and/or rudder movement. A speed is reached at which the nose or one wing can no longer be kept up and at this speed the nose or wing drops. This speed is taken as the stalling speed. When accurate measurement is required it is obtained by suspending the static pressure head sufficiently far below the aircraft to be free of the pressure field created by it and by the provision of a swivelling pitot head in a position away from local interference. The trailing air log is not a suitable instrument for these measurements. Alternatively, if an approximation to this speed will suffice, it can be obtained from the A.S.I. reading corrected for P.E., providing that the P.E. curve has been determined down to a fairly low speed.

On single seat aircraft the accurate method of measurement is difficult to apply and on types with violent stalling characteristics it may be dangerous.

8.2 *Speed in gliding flight.* The P.E. obtained by the method of para. 7.13 does not apply with the engine off and flaps down. Since the P.E. is of some importance in gliding flight, such as in beam approach and blind landing, measurements are required over a small speed range, including the speed for a landing approach. On two-seat and multi-seat aircraft this is obtained by a trailing static head or trailing air log. In single-seat aircraft, however, the measurement is not easy, and it is better to adopt one or other of the following methods:—

(*a*) Flight in formation with a calibrated aircraft.

(*b*) A variation of the level flight method of obtaining the P.E. by replacing the fixed tower by an observation balloon, past which the aircraft glides.

9. Speed-height Curves.

The speed of present aircraft varies with height in staircase fashion up to a certain height, then falls away in a continuous curve to the ceiling. It is important that the discontinuities in the curve are determined accurately and, contrary to popular belief, this cannot be achieved by speed measurements at the height in each supercharger gear at which the boost begins to fall. This is partly due to the difference in engine laws at constant boost and at full throttle which occasion different methods of reduction of speeds, etc., above and below full throttle height.

9.1 *Speed-height for maximum power.* There is no difficulty in obtaining accurate mean results from visual readings of instruments during steady motion tests. Top speed measurements cannot, however, be made during steady motion since there is a five minute limitation on maximum engine power and the steady speed corresponding to this power cannot be reached from cruising flight within five minutes. In consequence, a pilot experienced in level speed tests will first obtain at each height the approximate A.S.I. before the test proper is made. He will then make his approach from cruising speed to top speed by increasing speed and losing height as he gradually opens the throttle. As he approaches the pre-determined A.S.I. he will have regained level flight with the throttle fully open. The readings of the instruments will then be taken during the last two minutes of the five minute full throttle period. Speed tests should be made at not more than 2,000 ft. intervals, and continued in low speed supercharger to 4,000 ft. past the change-gear height. Conversely in high speed supercharger they should be started 4,000 ft. below the change-gear height. Accurate speed and reliable speed-height curves can be made in this manner on high speed single-seat aircraft by experienced pilots, but on multi-engined aircraft we find it necessary to carry a technical observer in order to relieve the pilot of all observations. The following quantities are observed: the altitude, engine r.p.m., boost, mixture setting and supercharger gear, intake pressure and temperature, and intercooler temperature, the A.S.I., and the position of any moveable cooling flaps, bomb doors, or other items likely to affect performance. At present it is our practice not to fit recording instruments for these measurements but, as stated in para. 9.4, more quantities have now to be measured and a greater accuracy is demanded than we have required in the past. Speed-height curves are of little value unless the details of all external and internal equipment likely to affect the speed are quoted.

9.2 *Speed-height for maximum cruising power.* These tests are more easily made, in general, than top speed tests because each run can be maintained to ensure a stabilised speed. At altitudes near the ceiling, patience is required, the degree of which increases as the cruising power to weight ratio decreases. On all aircraft there is a minimum A.S.I. below which level flight cannot be maintained easily. This limiting speed is usually set by the pilot during cruising speed tests; it corresponds to flight at a point so near the minimum of the curve of power required against speed that the excess of power developed over the minimum for level flight is just sufficient to cater for mild turns or for the recovery of height lost during bumps.

The height at which the cruising speed equals this limiting speed has been termed the " cruising ceiling." Some importance is given to the limiting cruising speed by operational pilots and because of this, together with its value in range and reinforcing flights, it is dealt with in greater detail in para. 10. The practical measurement of speed near this cruising ceiling requires skill because acceleration from one speed to another is low; at least 15 minutes should be allowed for the speed to stabilise.

9.3 *Speed-power curve at constant height.* In investigations of the effect on speed of the addition of items of external equipment, it is frequently useful to obtain (for each condition of the aircraft) a curve of speed against power at some definite height. At speeds near the lower end of the cruising range, the speed becomes increasingly sensitive to changes of power, weight or drag; furthermore, items of external equipment which affect the air flow over the wings sometimes act like " induced " drag in the sense that the drag increment increases with increasing incidence. Thus it is desirable to investigate the effect on speed over a range of speeds, and this may be achieved most economically by determining speed-power curves.

In such tests, the engine power is decreased in convenient steps from the maximum power, and the speed noted at frequent intervals; since the speed changes from step to step are not large, it is usually sufficient to maintain each

power for 10 minutes before decreasing to the next step. This test may conveniently be combined with the determination of the minimum speed for continuous cruising, for, by continuing the process to very low powers, the speed at which level flight becomes virtually impossible may be obtained.

9.4 *Developments* (see also Part VI). Recent experience has shown that engine powers and airframe manufacture are not sufficiently consistent to ensure like (within the range $\pm 1\frac{1}{2}$ per cent. at low altitude and $\pm 2\frac{1}{2}$ per cent. at high altitude) performance on all aircraft of the same type. In the field of experimental flight test work it follows, therefore, that the effect on speed of aircraft modifications such as change of exhaust, intake, propellor, radiator, finish, etc., cannot be made by comparing results on different aircraft unless:—

(*a*) The power of the engines is measurable at the time and height of the test, and

(*b*) We have a more precise knowledge of the effect on speed of overall external surface finish and a method of categorising the finish.

It also follows that a series of such tests made on the same aircraft are conducive to misleading conclusions, or incorrect decisions, if the engine powers fade or replacement engines are fitted during the test series. Replacement engines and/or carburettors in the middle of a series of comparative tests are a menace now that engines and their accessories are mass produced, and much test work has to be started afresh simply because the power, especially at high altitude, of the engines is not known.

An easily fitted torquemeter is the most urgently required instrument in the performance testing of aircraft. After this come measurements such as charge temperature, and the automatic registration of all instruments. Reference should also be made to a differential tachometer developed by Messrs. Rotols, which will enable more precise observations of the engine speed than is possible with present engine speed indicators.

10. Minimum Speed for Continuous Cruising.

In long range operations and in reinforcing flights over long distances where conservation of fuel is a study, a knowledge of the minimum speed for comfortable continuous cruising is of great assistance to executives and pilots alike. Indeed, it is essential knowledge to those who plan night operations, because the weight that may be carried has to be balanced against the maximum operational cruising height which is dependent on this speed.

We have found that this speed is more reliably determined during cruising speed (para. 9.2) and fuel consumption measurements (para. 13) than by pilots' observations from general handling flights. Values of this speed obtained on many types in the above manner have agreed reasonably well with the opinions of the Commands.

If $V_{i\ mp}$ is the speed for minimum drag power in level flight, then a good approximation to the minimum speed for continuous cruising is $1.35\ V_{i\ mp}$, the 35 per cent. increase being accounted for partly by the loss of propellor efficiency at low speeds and partly by the necessity for maintaining a small power margin for mild manœuvres. In the absence of experimentally obtained data it is possible to define the "cruising ceiling" as the greatest height at which the speed $1.35\ V_{i\ mp}$ can be maintained at maximum cruising power.

11. Partial Climbs.

Before measuring the climb performance, it is first necessary to determine the A.S.I. for the maximum rate of climb by making partial (or saw-tooth) climb tests.

11.1 *All engines working*. In order to determine the best climb performance of an aircraft, it is necessary to know the best climbing speed at all heights from

ground level to ceiling. For an aircraft with an engine having only one supercharger speed, it is found that the best climbing speed varies little from ground level to the full throttle height, and then falls away from this height to the ceiling, more or less linearly; three sets of partial climbs are thus needed, one below full throttle height, one a few thousand feet above full throttle height, and one as near as possible to the ceiling. With two-speed superchargers, it would appear at first sight that six sets of partial climbs would be necessary, but, in practice, it is found that the best climbing speed varies little between ground level and the full throttle height in the higher supercharger gear, so that the same three sets of partial climbs will suffice, with the possible addition of a fourth near the change-gear height.

FIG. 6.

Automatic observer for general performance tests.

The procedure found best for partial climb tests, when an observer can be carried, is to obtain steady climbing conditions at the chosen speed and then to read a Kollsman altimeter at ten-second intervals over the selected height range (which should permit readings to be taken over a period of at least two minutes). Height increments which are clearly inconsistent can then be discarded and the remainder averaged. It is important to take into account the change of rate of climb due to weight variation during a series of runs, otherwise the shape of the curve of rate of climb against speed may be distorted, and the speed for maximum rate of climb incorrectly assessed. A convenient method is to cover the required speed range systematically up and down; i.e., the range 120-160 m.p.h. A.S.I. should be covered in the order 120, 130, 140, 150, 160, level, 160.

150, 140, 130 and 120. The mean line of the resulting horn-shaped series of points will give the correct shape of curve for the mean weight. Alternatively, the weight variation may be noted by flowmeter, and each rate of climb corrected to a common weight.

The same technique can be used on single-seater aircraft which have a comparatively low rate of climb, but on modern, fast climbing fighters the pilot is unable to do more than time the aircraft over a single large height interval, and the automatic observer, shown in Fig. 6, is now being introduced for such tests.

Partial climbs must be made with care; in particular it is necessary for the descent to be made at the speed of the following partial climb, for the change of flight path to be made gradually as the throttle is opened and for steady motion conditions to exist before the lower height level is reached.

11.2 *One or more engines "dead."* On multi-engined types, partial climb tests with one or more engines "dead" are required to answer the questions "Will the aircraft maintain height at this weight after engine failure?" and "What is the best speed for maximum rate of climb or minimum rate of descent after engine failure?" The tests will also give a rough answer to an alternative form of the first question—"At what weight will the aircraft maintain height after an engine failure?"—but it will be realised that the answer to this question will depend widely on the air temperature and the power of the individual engines installed. The method of test is similar to that used when all engines are operating, except that it may be necessary to continue each run for a longer period of time to obtain satisfactory results. These tests are intimately connected with the corresponding handling tests (para. 23) since it is essential that the handling characteristics shall be satisfactory in asymmetric flight at the speed giving the best climb performance.

The propeller control of the "dead" engine should be in "low speed" for the majority of these tests, but sufficient tests with the propeller feathered to determine the gain due to feathering should also be made. The drag of the wing containing the "dead" engine should be reduced to a minimum by the closing of the cooling gills, shutters, flaps, and the like.

Should the one-engine performance of a twin be good in that it can climb easily at the load to which it can be reduced, no further tests are necessary. The worse the performance, however, the greater is the amount of test work required. For example, if it is doubtful from the results that level flight can be maintained, a flight of long duration with the propeller of the "dead" engine feathered is required. This should for preference be made at a low height (the pilot can always lose height if an engine cuts and thus descend to the height in medium supercharger at which the engine power is a maximum, but he may not be able to climb to this height should the "cut" be experienced at a lower altitude) and at the maximum weight less the load which may be dropped. Fuel flow, oil and coolant (or cylinder) temperatures should also be observed during this flight.

12. Ceiling Climb.

Having determined, for all heights, the speeds which give the maximum rate of climb, a climb to ceiling is then made using the maximum climb power and the best climbing speeds; this climb gives the best possible climb performance of the aircraft in the form of a time-to-height curve, and, by differentiation, in the form of a curve of rate of climb against height. As for partial climbs, visual reading of the instruments is satisfactory on aircraft which can carry an observer, and on single-seaters with a low rate of climb. On fast-climbing single-seater fighters, however, it is becoming increasingly difficult for the pilot to take accurate observations of all instruments in the time at his disposal, and we are now introducing automatic observers for this test.

Ceiling climbs are sometimes required under conditions other than those giving maximum performance. Firstly, it sometimes happens that the stability or control

characteristics of an aircraft at its best climbing speed are such that accurate flying is tiring to the pilot, particularly in conditions of poor visibility, or it may be that the engine cooling is inadequate at the best climbing speed; in such cases, a ceiling climb may be required at a higher climbing speed to determine whether as a temporary expedient the stability or cooling characteristics can be made satisfactory without an unacceptable loss of performance. And, secondly, ceiling climbs are sometimes made in simulation of an operational technique used for special reasons—for example, a climb at maximum weak mixture cruising power, which may effect an economy in fuel consumption.

As a safeguard against error in the best climbing speed at, or close to, the ceiling, the pilot should, in one climb at least, determine the effect of changing speed slightly each way from this speed.

The location and direction of flight should be recorded so that the results can be corrected, if necessary, for wind gradient.

12.1 *Developments.* Except that automatic registration of all instruments on high speed climbing aircraft is a present need, the same developments as at para. 9.4 apply.

13. RANGE.

Before a range flight may be made, accurate measurements are required of the fuel flow over a wide range of power and flight conditions. From these results, suitably corrected to standard conditions, the specific range in air miles per gallon at each of a large number of combinations of the factors involved is obtained, from which, in turn, the optimum conditions can be selected and the maximum operating ranges in still air determined. An actual range flight is then required as a practical check on the ideal range.

13.1 *The flowmeter.* A suitable instrument for the measurement of fuel flow, and the one in most general use (in Britain) is the Kent flowmeter. This is an accurate, reliable and consistent instrument which can be installed by a simple modification to the fuel system. It comprises two units; a transmitter which is installed in the last fuel pipe line to the carburettor, and a receiving unit suitably mounted in the cabin. The transmitter is a rotary volume flowmeter which causes electrical impulses to be transmitted to the receiving unit, which is fitted with a stop watch mechanism so arranged that the reading is given directly in gallons per hour. A Veeder counter registering gallons passed is also provided in the receiving unit. A flowmeter for each engine is fitted.

13.2 *Object of fuel flow tests.* The main object of the tests is to determine how to obtain the maximum range and the manner in which the range is affected by the variables involved. These variables are:—

These four govern the thrust power required by the aircraft.	Airspeed.	
	Flying weight.	
	Altitude.	These four, for a given selection of supercharger gear and mixture control position, decide the rate of fuel flow.
	Air temperature.	
	Engine r.p.m.	
	Boost pressure.	

The range is also affected by the choice of supercharger gear and of mixture control position, where such choice is available.

From the fuel flow measurements we can determine the optimum air miles per gallon at each height, together with the airspeed and combination of engine conditions required to obtain it. At the same time sufficient evidence is obtained to provide information on a number of other points, some of which are:—

(*a*) Effect of variation in height on the optimum air miles per gallon and on the conditions required to attain it.
(*b*) Height for optimum range.
(*c*) Best supercharger gear at any height.
(*d*) Effect of weight changes on the range.

(*e*) Effect of using hot air intakes.
(*f*) Losses in range resulting from non-adherence to the optimum conditions.
(*g*) Fuel consumption while climbing.
(*h*) Fuel consumption at combat powers on fighters.
(*i*) General rules on range flying of the type concerned.

In addition to these directly relevant features the results of the tests can provide considerable information concerning the relative efficiencies of the engine-propeller installations or the relative aerodynamic properties of different aircraft types.

During these tests an independent assessment of the minimum speed at which continuous flight can be maintained and the minimum speed for comfortable continuous cruising is obtained. No speed lower than the latter speed can be recommended for range flying.

The tests will, of course, also provide information from which the maximum endurance of the aircraft at any height can be determined.

13.3 *Tests.* The specific tests made on any aircraft will naturally depend on its type, function and proposed operational use. As a general rule, however, a series of runs is made in each supercharger at a height slightly below the full throttle height for maximum weak mixture cruising conditions, in which fuel flow and speed are measured at all combinations of r.p.m. and boost (in steps of, say, 100 r.p.m. and 1 lb./sq. in. boost) within the weak mixture cruising range, down to the lowest values at which it is possible to maintain flight or to maintain smooth running of the engine. Where there is a choice of mixture control these tests will be made, using weak mixture, but a few tests are also made in rich mixture at each height at powers outside the weak mixture range. These rich mixture checks give the losses in range incurred by the use of rich mixture, the consumption under combat conditions on fighters, etc.

The results of the above tests after correction to standard conditions are conveniently plotted in the form of air miles per gallon—A.S.I. " grid," an example of which is given in Fig. 7. From this diagram it is possible to obtain the most economical speed with the corresponding optimum air miles per gallon, and the engine conditions required to give this condition. It will also show whether the " low r.p.m.-high boost " law for obtaining maximum economy holds for the type, or, if not, what alternative rules apply. Few aircraft have been found to disobey this rule and it has been found that non-compliance signifies inconsistent carburation or propellers not designed to absorb the power at low engine speeds.

Tests at other heights can then be confined to what are termed " envelope " conditions; that is, the engine conditions which will give the maximum economy at any given speed, and which are represented by the solid line in Fig. 7. The other heights tested will usually include a height near the maximum practicable operating height in each supercharger gear, and, in the case of types designed for low altitude work, a height near sea-level.

On types such as heavy bombers where large weight changes may occur in the course of an operational flight, due to consumption of fuel and dropping of bombs, it is necessary to repeat one or more of the tests at a different weight to determine the effect of changes in weight on air miles per gallon.

Tests are also required on which the consumption on the climb in weak and rich mixture is measured, and a few repeats in level flight, using hot air.

It is important that the carburation of each engine is checked as described in para. 14.2 before these tests are made.

13.4 *Test technique.* The actual technique during the flight tests is fairly straightforward. Accuracy is, of course, essential in the flying of the aircraft and in setting the desired engine conditions and reading the instruments. An accurate check on the weight of the aircraft must be kept during the tests, which

is best done by taking frequent readings of the flowmeter Veeder counters and checking the quantity of fuel required to re-fill the tanks after landing.

It is also important to allow ample time for the speed and fuel flow to stabilise under each condition tested. Speeds, in particular, may take a long time to stabilise at economical cruising speeds and slower, especially in large bombers where accelerations following small changes in power are low.

13·5 *Range flight.* It will be appreciated that the range determined from fuel flow readings obtained during short steady flight runs in good atmospheric conditions will represent the upper limit to the actual range which can be achieved. As a final check on the range of the aircraft, a range flight is made in which the flight drill recommended as a result of the tests already described is used, and a known quantity of fuel is consumed. A comprehensive log should be kept during this flight in which the readings of all relevant instruments, including engine and oil temperature gauges, are recorded at frequent intervals. As well as providing

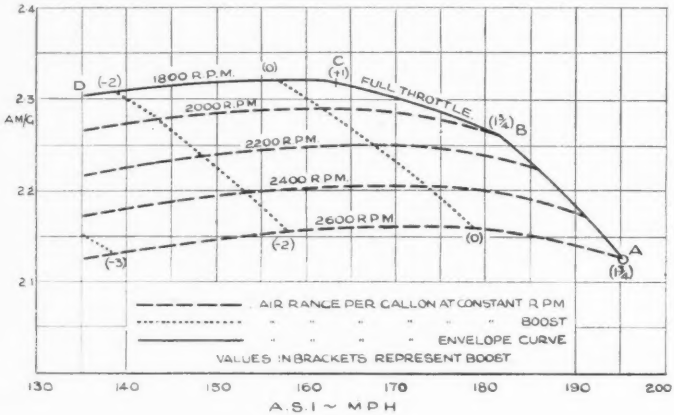


FIG 7

AIR MILES PER GALLON—A·S·I DIAGRAM

A. DENOTES MAXIMUM POWER FOR WEAK MIXTURE CRUISING.
B. " " R.P.M. AT WHICH THE THROTTLE IS FULLY OPEN.
C. " MINIMUM ENGINE SPEED AT WHICH PROPELLER WILL CONTROL SATISFACTORILY.
D. " MINIMUM A·S·I AT WHICH HEIGHT CAN BE MAINTAINED AT THE MINIMUM ENGINE SPEED.

a direct check on the range, the flight will also provide information on other items; e.g. whether the cooling is adequate at the conditions involved; whether all the fuel contained in each tank can be used; whether the recommended speed can, in fact, be comfortably maintained by the pilot for long periods, etc. If possible the tanker used to re-fill the fuel tanks should be weighed before and after so that the weight of fuel used can be directly determined.

Though outside the scope of tests as defined in para. 2, it should be noted that there are invaluable by-products from a well organised range flight of a large aircraft. The radio, heating and navigational facilities can be collectively assessed; the comfortability of all crew stations and the efficacy of accessories such as automatic controls, windscreen wipers, glycol spray, can be determined; logs kept of engine and oil temperatures; suitability of the aircraft for night flying, etc., and in all probability data on cloud flying can be obtained.

14. Cooling Tests of Engine Installations.

These tests comprise measurements of engine coolant (or cylinders in the case of an air-cooled engine) and oil temperatures, from which the suitability of the radiator and oil cooler under particular conditions of flight and atmospheric conditions are assessed. Subsidiary temperature measurements such as engine bay, compressor, magneto, etc., are also made, but these are straightforward measurements and will not be discussed.

The main factors governing the cooling of a given aircraft, engine and cooling systems are, at a given height:—

(*a*) Carburettors—the mass production of this accessory has resulted in wider tolerances of manufacture.

(*b*) Exhausts—whether open ejectors, slotted shrouded pipes, or swept back individual pipes, etc.

(*c*) Intakes—whether temperate or tropical, with or without cleaners, etc.

(*d*) Charge temperature.

(*e*) Intake temperature.

Alternatively, for given items (*a*) to (*e*), the cooling will depend on the mass flow of air through the radiator (liquid cooled) or past the cylinders (air-cooled) and oil cooler.

Thus, for a given power as indicated by r.p.m. and boost, the suitability of the cooling system changes with those aircraft modifications which affect drag and/or weight and with some engine accessories. Hence cooling tests must be made for the two extreme combinations. Once with the maximum drag of the alternative loads represented and again with the maximum weight (with attendant drag) represented.

14.1 *Tests made.* The cooling requirements and the conditions of flight under which these requirements must be met have been formulated and it is not necessary here to recapitulate them. The method of assessing the suitability of the systems at the atmospheric conditions considered has also been specified. Since the above conditions of flight were drafted, information has come to hand which may lead to minor modifications. This information is given in Appendix III. An additional test to those mentioned above; namely, measurements during one engined flight of " twins " at the emergency power conditions are made during long flights on one engine (para. 11.2).

14.2 *Observations taken and instruments fitted.* Though the official publication above does not call for the fuel flow to be measured and relevant observations to be made on all engines, we have found that both are necessary. Fuel flow measurements during cooling tests are particularly important on air-cooled engines (British and American) and it is necessary to check the carburation of each engine before the cooling tests are made. This is fairly easily done on carburettors with automatic " weak " and " rich " when propellers lockable in pitch are fitted. There should be not more than 3 per cent. drop in r.p.m. between " rich " and " weak " mixture maximum cruising powers or, say, 12 per cent. drop in fuel flow. Where single lever carburettors are fitted the fuel flow at ground level is compared with the fuel flows at altitude with allowance for density, etc., in accordance with the air flow formula.

In addition to the observations of the standard fitted instruments, observations are made of inlet and outlet temperatures of the radiator and oil cooler. For air-cooled engines each cylinder head temperature is measured by multi-point pyrometers with ice-cold junctions. In the past one receiving unit only per set of pyrometers was fitted with jacking points for each cylinder.

On twin and multi-engined aircraft one engine should be retained unaltered throughout a series of tests involving modifications, so that a basis of comparison

can be maintained. This is a good insurance against varying atmospheric conditions.

14.3 *Developments*. More hours of test flying have been made at the A. & A.E.E. on this item in the last four years than on any other subject, and, in general, air-cooled types have occasioned more attention than liquid cooled types. The reason for the latter statement can be simply stated, but the reasons for the former are more profound. If the coolant radiator is not adequate to meet demands its size can easily be increased, whereas it may be a difficult problem to increase the air flow past the cylinders of the air-cooled engine. Also, the coolant temperature—the criterion of measurement—is dependent on the mean temperature of the cylinders, whereas one of the criteria for the air-cooled engine is the temperature of the hottest cylinder. It is evident therefore, that the tests are more stringent for the air-cooled engine than for the liquid-cooled.

One reason why cooling tests have occupied, in general, more flying time than other tests is because they are one of the few tests in which definite requirements have to be met in definite conditions of flight. Hence on troublesome systems where modifications are frequent, many repeat tests are necessary. There is another, and probably more potent reason. Air-cooled installations seldom meet requirements at the first test and this fact would imply that the designer of the installation is not in possession of sufficient flight test data to enable him to forecast accurately the design of the cooling passages. It as well, therefore, to consider whether we are making sufficient fundamental observations during this flight test work. The main factor upon which the cooling of air-cooled types depends, that is, the mass flow over the engine, is not measured. There are also other relevant data which are not observed, such as B.H.P., charge and intake temperature, and possibly exhaust back pressure.

The requisite instruments to measure such quantities (except B.H.P.) can be easily provided and fitted when the engine installation is being assembled in prototype and first production aircraft. Such measurements as indicated above would, in time, provide invaluable data and possibly insure the aircraft industry against perpetuating the same mistake made by the British motor car industry, that is, undercooling the engine installation in order to get a doubtful gain in efficiency.

The importance of measuring air flow through oil coolers has been realised for some time because of the so-called "coring" troubles. Three methods of measurement are being tried, (*a*) the employment of a battery of pitot heads, (*b*) by static pressure rings, and (*c*) by a grid of electrically heated wires past which the flow is measured by the change of resistance. These measurements will in all probability lead, in their turn, to the measurement of air temperature rise across the cooler so that the heat balance established can be used to grade the accuracy of the observations.

On the instrument side of this work we have made a compact comprehensive photographic recording instrument which will photograph simultaneously the temperatures at each of the 18 cylinder heads of air-cooled engines. This instrument has the dimensions $20'' \times 12'' \times 8''$.

15. Landing and Approach.

We do not at present measure the landing distances on all aircraft. Such measurements are only made in particular cases where the merit of some particular feature is being studied. For these measurements the same camera is used as for take-off. In F.A.A. types the rate of descent for different forward speeds is measured over a range of engine powers and r.p.m. in order to determine the most suitable engine conditions for preliminary carrier landings.

PART III.

Flight Characteristics.

16. General Outlook.

Some few quantitative measurements have always been made, but, it is true to say that, until recently, the flight characteristics of new types were developed from pilots' observations alone. All the world knows of the excellence of some of our types operating to-day and I am happy to have this opportunity of suggesting that a large slice of the credit should be given to the test pilot of the past. It is also relevant to record that our standards of acceptance are continually being modified (qualitatively) to take account of information collected and contributed by the Operational Commands. Our basic method of developing new type aircraft is undoubtedly sound, but aircraft are growing larger and more complicated; the effort to make modifications is increasing, and the cost of developing troublesome types is already huge. In consequence we must strive continually to reduce to a minimum the flight development period, by aiding the pilot to get more information per flight and, by reducing the trials and error period. This can best be achieved by making measurements of those quantities which will enable us to grade, with precision, some of the adjectives at present common to all handling reports. This process is gradually being applied as the following paragraphs will show.

17. Trim—Longitudinal, Directional and Lateral.

Changes of trim can be occasioned by a change of speed, a movement of the centre of gravity (c.g.) and by the operation of the many aids to flying, fighting and bombing provided. It is undesirable to have large changes of trim about any axis with (1) speed or (2) power; to create out of trim conditions by working any device such as (3) landing flaps, (4) brake flaps, (5) reversible pitch propellers, (6) cooling flaps, (7) undercarriage, (8) gun turrets, (9) bomb doors, (10) dropping bombs, (11) gun firing. At some condition of flight such as diving at high speed, during combat or ground attack, dive bombing, etc., each one of the above is important. For example, (1) is conducive to loss of control in cloud flying and to lack of precision in dive bombing, (2) is important in dive bombing and in baulked landings, (3) and (7) in take-off and landing, (4) in day and night fighters, (5) in landing, (6), (8) and (11) in combat, and (10) in precision bombing.

The insignificant thermostatically controlled cooling flap may not cause much change of trim. It may be cursed by the fighter pilot, however, if it clicks open at the moment he has the enemy in his gun sight. The same applies to the turret gunner should the rotation of the turret cause either yaw or pitch. The above examples are not exhaustive, but they are sufficient to show that a thorough examination of all trim effects should be made.

Changes of trim can be divided into five categories:—

(*a*) Changes due to speed changes at a given c.g. (affects all axes).
(*b*) Trim changes due to changes of power (longitudinal and directional).
(*c*) Change of trim with c.g. position (longitudinal).
(*d*) Changes at a given speed caused by the operation of the many services (mainly longitudinal and directional).
(*e*) Change of trim (longitudinal) with Mach Number.

Those trim changes under (*b*) and (*d*) which tend to tail heaviness should be noted in conjunction with the aft limit of the c.g. and vice versa. Precise angular measurements of the trimmers are not required in tests (*a*) to (*d*) so that observations from the fitted indicators will suffice. For test (*e*), however, the precise angles must be measured. Before the above measurements of trim are made, particularly those under (*a*) and (*e*), the shrouds in front of all controls and trimmers should be carefully examined and straightened out or replaced if any

signs of distortion or flexibility are observed. During the measurements under (a) the pilot must be particularly careful to be in trim directionally before assessing the change of lateral trim between two speed values because there is on some types a pronounced interaction of trim about their respective axes (see also para. 25 (iv)). The technician must also distinguish between large changes of trimmer angles and changes of trim. For example, an aircraft with an inherently large change of directional trim with speed may require a large change of trimmer angle should the rudder be heavy and a small change of angle if the rudder is light.

At present the changes of trim present in an aircraft are accepted or rejected according to its role in conjunction with its flight and control characteristics.

No aircraft should be provided with trimmer controls more powerful than is requisite to trim out the foot or hand load at any of the above conditions (including asymmetric flight—para. 23) of flight within the design speed limitations. The trimmer limit stops should therefore be adjusted to restrict their angular movement within the required range, plus, say, 1° to allow for differences between aircraft. Tests should then be made as indicated in para. 6.1 (7) to determine the speed at which the pilot can overcome the trimmer when set to the maximum angle.

17.1 *Developments.* We do not know the limiting foot or hand force within which each aircraft type can be accepted for trim changes, but data on this subject will be collected when control column and rudder bar force recorders are fitted. Also, as stated in para. 6.3, Desyn indicators will probably be fitted to all control surfaces and trimmers. This will enable the actual trimmer angles to be measured.

18. Stability—Longitudinal, Lateral and Directional (Excepting Low Speeds).

In most flight manœuvres stability and control are inseparable, but it is possible to deal with some tests separately and for convenience the subjects are given different paragraphs.

Before any tests under this heading are made, all control circuits are examined, friction and backlash deleted if possible, distorted shrouds in front of controls or trimmers should be straightened or replaced, indicators should be fitted to show the position of all operable flaps such as thermostatically controlled radiator flaps not under the control of the pilot or engineer. Those external features listed likely to have an influence on the results should be listed.

18.1 *Longitudinal stability.* The stability characteristics can be fairly well established from a combination of the following tests:—

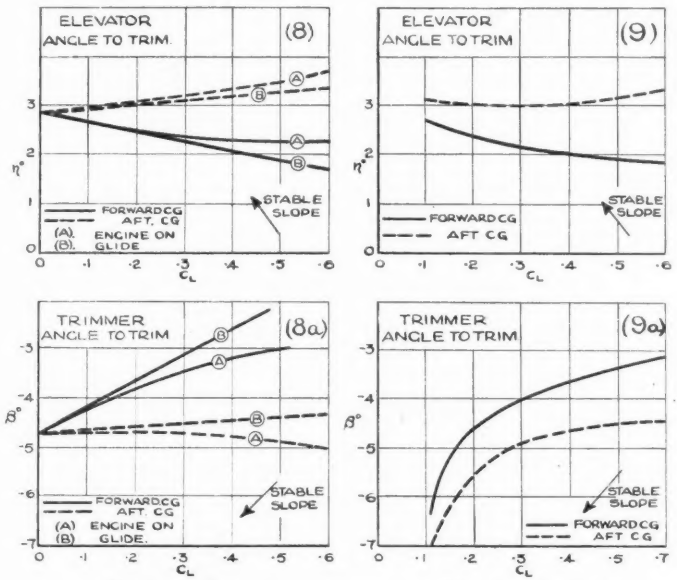
(*a*) Static stability—engine on and off.
(*b*) Pilots' assessment from general handling, including flight in bad weather, clouds, etc.
(*c*) Phugoids.
(*d*) Measurement of stick force per unit of " g " (acceleration of gravity).
(*e*) Measurement of stick displacement per unit of " g " or of C_L (lift coefficient).
(*f*) Identification of the quick period oscillation.

Tests (*a*) to (*d*) and (*f*) are common British practice. Test (*e*) is also of value, however, and can readily be combined with (*d*). Tests (*c*), once the high-light of stability testing, are falling in importance in Britain and the U.S., though they still contribute information which at times is valuable.

18.11 *Static stability.* As early as practicable, static stability tests are made. The reasons for making these tests, the observations required, and the method of obtaining the " stick fixed " and " stick free " neutral points from the results, are adequately explained in R.A.E. reports circulated to

firms. There are, however, one or two by-products from these tests which it is as well to mention. First, precise measurements of all trimmer angles are obtained throughout the speed range for the extreme c.g. positions. Secondly, since a large c.g. shift is required during the tests, flight throughout the speed range is ensured at an early stage in the flight testing of the type over the complete c.g. range. Thirdly, the sensitivity of all trimmers and a rough idea of the interaction of lateral and directional trim is early obtained.

The curves of η and β against C_L from which the neutral points are determined, may reveal, by unorthodox shape, peculiarities such as tailplane twist, elevator distortion or excessive stability at high speed. Separate tests can then be planned to identify the feature for further exploration. Figs. 8 and 8a show actual examples of an orthodox aircraft, while Figs. 9 and 9a give examples of a peculiar set of trim curves caused by tailplane twist.



FIGS 8 & 8a
"CONVENTIONAL" AIRCRAFT
(NO TAILPLANE DISTORTION)

FIGS 9 & 9a
"CONVENTIONAL" AIRCRAFT
(WITH TAILPLANE DISTORTION)

CURVES OF ELEVATOR & TRIMMER ANGLES TO TRIM AGAINST C_L

18.12 *Pilot's assessment.* The pilot will note the elevator load in turns, in flight at increments of speed from a trimmed speed and the characteristics at climbing speeds between the take-off speed and the best climbing speed.

18.13 *Phugoids.* These are made with engine ON and OFF. They are of little value if the aircraft is statically stable to a fair degree because in such circumstances tests at paras. 18.11 and 18.12 give a more conclusive answer. On the other hand, the neutral points are not so accurately determined when there is little or negative static margin and the phugoid is

then useful in showing *the rate* at which the speed diverges from the trimmed speed. In other words, the first phase of the phugoid is useful in conjunction with the tests of paras. 18.12 and 18.14 in fixing the most aft c.g. that can be accepted for special and restricted duty—a requirement of war-time aircraft.

18.14 *Stick force and/or displacement per "g."* Though these tests help in the general stability assessment, they are more conveniently described under control (para. 24).

18.15 *Quick period oscillation.* Unlike the phugoid (constant incidence) this oscillation is of quick period and involves incidence variations at constant speed. It is most likely to be noticed on aircraft with

(*a*) Inadequate damping.
(*b*) Small elevator hinge moment.
(*c*) Elevator mass under-balance.
(*d*) Big moment of inertia.
(*e*) Small friction in elevator control circuit.

To test for this oscillation the elevator is moved smartly backwards and the stick quickly abandoned. The test should be repeated at high speed. If high accelerations and a persistent oscillation are experienced, remedial action must be taken.

Since the presence of friction is favourable and bumpy atmospheric conditions unfavourable, these tests should be made at low altitude where the friction is likely to be least and weather conditions worst.

18.2 *Lateral and directional stability.* Except where there is no change of lateral and directional trim with speed and no friction in the controls, it is not possible to assess separately the stability about the longitudinal and vertical axes. No aircraft has these virtues; hence lateral and directional stability are assessed in the main together. In addition, unless there is provision for the locking of the rudder and aileron controls, the stability about the above axes cannot be free of control interference.

Despite the above limitations the age old test of depressing a wing through various angles and smartly returning the stick to neutral contributes its part to the general assessment of lateral stability. The complementary directional test is also contributory; likewise the stick free excursions in yaw and roll in bumpy weather contribute to the pool of information. These tests are followed by one-control tests, i.e. turns by (*a*) rudder only (stick held neutral), (*b*) aileron only (rudder bar held neutral), and (*c*) aileron only (rudder free). During these tests the pilot notes the characteristics of the turn, the rate of turn which can be reached, the sideslip on entering and recovering and the difference between turns for gentle, quick and progressive application of the working control. The aircraft is tested in sideslip (*a*) by steady flat turns and (*b*) by straight sideslips. Of the above tests, the straight sideslip undoubtedly gives most reliable directional stability data. It also reveals any tendency for the vertical tail surfaces to stall and for the rudder to lock over.

On twin and multi-engined types the motions in jaw and roll are recorded subsequent to a quick engine "cut." Pilots are invited to allow a roll to 45° before taking over control and to note the speed range within which this is practicable. Tests are then continued under control, outside this range, down to speed of take-off, if practicable.

Up to recently, visual observations only were made during these tests and the final assessment of the adequacy of stability was pronounced after studied debate by pilots and technicians, followed by careful summing up.

18.3 *Developments.* With Desyn indicators to record control and trimmer angles, and stick recorders for control forces, the longitudinal stability tests defined are adequate to ensure the accuracy required. The lateral and directional stability tests will require, in addition, a sideslip vane recorder. It may also

be practicable to supplement the tests by applying a known yawing moment on one wing and measuring the sideslip and rudder angles to fly straight.

It is also equally important to train pilots to a better understanding of these complicated subjects and their interaction on the general manœuvrability of the aircraft. In particular, the A. & A.E.E. might be supplied with an instructional aircraft provided with wing tips controllable in dihedral and a fin variable in size both capable of adjustment in flight by the pilot.

19. CONTROLS—ELEVATOR, AILERONS AND RUDDER.

All three controls are tested throughout the speed range and at the extremes of altitude for: their tendency to centralise from small and large deflections and, for any tendency to overbalance during well and badly executed manœuvres. All trimmers are tested at the ceiling to ensure free operation in very cold temperatures.

19.1 *Elevator.* The criteria of elevator power are most likely to be experienced in a baulked landing (para. 26), in recovery from dives, in a normal landing with c.g. forward, in diving (dive bombers) where there is a large change of trim with dive brakes, in take-off (tail wheel types) at the early part of the run, or, in diving

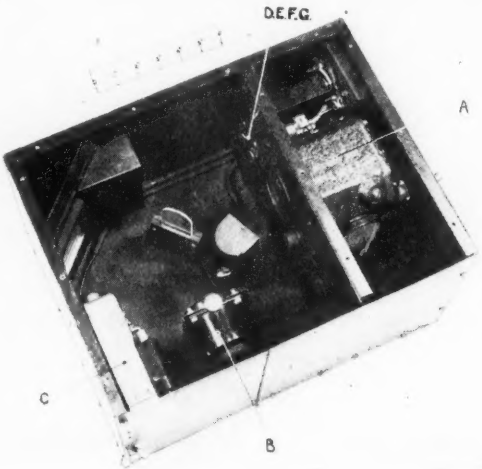


FIG. 10.

Automatic observer for rate of roll tests.

due to engine cutting and in making tight turns. The maximum loads are most likely to be experienced during one or more of the above phases of flight. The quantitative measurements made are described in para. 24. The effect of elevator movement on the rudder bar and vice versa is investigated.

19.2 *Ailerons.* The criteria of aileron power are most likely to occur in sideslip, in take-off to correct for wing drop (particularly cross wind take-offs), the approach to land (flaps down) in bumpy weather, in the final turn to land on a carrier deck, in the initial stages subsequent to an engine failure, and from straight flight where a high rate of roll is required at all speeds. If the ailerons have sufficient power to meet the above conditions, all manœuvres required of the type should be practicable. Special aileron control tests are made throughout the

speed range from straight and steady flight for the measurement of the rate of, or time to, roll through 90° (or 180°), the aileron angle and the stick force being measured. These tests are repeated but as the 90° bank (a lesser angle for heavy aircraft) is approached, the control is reversed to determine whether larger stick forces are required to reverse the roll than to start it. The A. & A.E.E. automatic observer used for these tests is shown in Fig. 10. "*A*" is a free gyro, "*B*" a watch, "*C*" a camera, and "*D*," "*E*," "*F*" and "*G*" are Desyn indicators connected to read angle of roll, aileron angle, rudder angle (supposed fixed during tests) and stick force. The overall dimensions of the observer are 16″ × 12″ × 8″.

19.3 *Rudder(s)*. The criteria of rudder power are most likely to occur in take-off (to correct swing), in the landing approach in bumpy weather, at the touch-down in a cross wind landing, in asymmetric flight with one or more engines "dead," in the initial stages subsequent to an engine failure, and in sideslip if there is a high degree of directional stability, or should the ailerons be particularly effective and light.

19.4 *Developments*. Again, the fitting of Desyn indicators (for photographic recording) to all control surfaces will establish whether the full angular deflections of the controls are used and under what conditions of flight. Together with control force measurements they will do much to speed up test work by supplying the answers to such questions as "Was the elevator fully back, or, was it too heavy to be pulled fully back?" and eliminate those questions such as, "How can you be sure that the rudder was not moved during the aileron control tests?"

20. Stability and Control at the Stall.

The usefulness of the extensive research work made on this subject in the past is reflected in the generally excellent behaviour of present types at and close to the stall. The tests made on present types are, in the main, precisely the same as those laid down many years ago. Particular attention is given during the tests to bring out the effect of cooling gills or flaps, drag flaps, brake flaps, ventilators, scoops, and the like. The aircraft conditions which give the worst behaviour are tested for different engine powers. No special instruments are fitted for these tests unless the behaviour experienced requires further investigation, which, over the last three years has been very rare. Should a single-engined type exhibit a tendency to spin during these tests, spinning tests will be necessary.

21. Spinning.

Excepting trainer types, spinning tests are not now made to determine the characteristics of the spin. Instead, attention is given to the behaviour on entry to the spin and on recovery subsequent to two turns. In other words, the tests are made in order to ensure recovery should an incipient spin occur. Tail parachutes are always fitted, but apart from this equipment, no special instruments are fitted and the only observations made are height lost in entry and recovery, and the number of turns required before recovery is complete.

22. Steadiness in Controlled Flight.

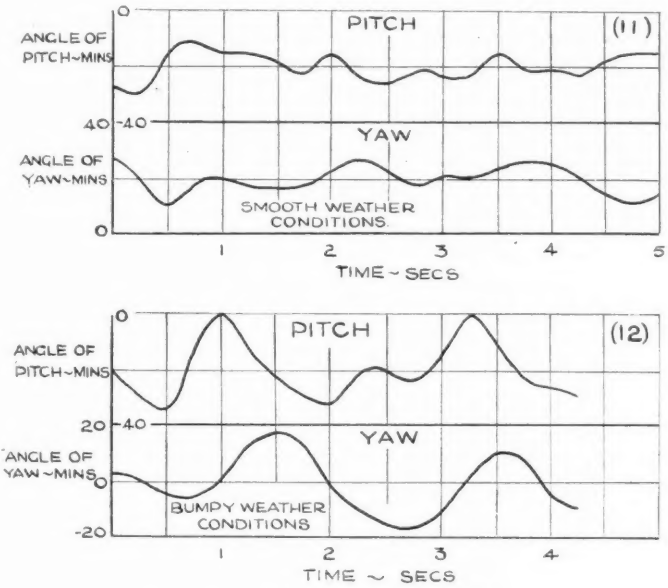
The transport which continually hunts and weaves, the bomber which wallows, the fighter which has to be flown continuously, and aircraft of any type which require great concentration from the pilot in clouds, all suffer from a malady which may not be revealed from stability tests. In other words, stability and steadiness, though related, are not synonymous. In addition, it is inconsistent to provide the bombardier with a precision bombsight without endeavouring also to make the bomber steady. Likewise, in ground attack where medium speeds have to be considered, the fighter should possess rock-like steady characteristics

when the controls are held fixed, and the aircraft must respond with precision following tiny movements of the controls. Standard tests have not yet been devised, but some evidence has been collected:—

(*a*) On fighters by an examination of camera gun film records (pitch and yaw only) from ground attack results (A. & A.E.E.),

(*b*) From steady motion level flight tests in bumpy weather on two twin-engined aircraft, one with a high degree of static stability and the other with negative static stability (R.A.E.), and

(*c*) On bombers from observations of the altitude of the sun given by a recording bubble sextant (A. & A.E.E.).



FIGS 11 & 12

RECORDS OF PITCH & YAW AGAINST TIME

22.1 *Camera gun film records.* An analysis of pilots' statements and records from many different types of aircraft show that the rudder and elevator controls should be light and effective for small angles round about a speed of 250 m.p.h. A.S.I. Sample records of yaw and pitch plotted on a time basis are given in Figs. 11 and 12 for two typical fighters. Pairs of records are given for each aircraft: one record shows the best obtained under good conditions and the other an average result under normal bumpy conditions. Apart from the measured excursions in pitch and yaw which are obtained from these tests, we have found that the tests are most useful also to the pilot in that they enable him to assess the sensitivity of the controls for small movements.

22.2 *Rough weather steadiness.* During these tests, made by the R.A.E., the normal and lateral accelerations have been recorded, together with speed and

altitude. The results indicate that the more stable aircraft is also the steadier. This result, however, does not prove that it is steadier because it is more stable, since the controls of the stable aircraft (which are known to be very good) may be better for small deviations than those of the lesser stable aircraft. The results confirm, however, that more work of this nature is necessary.

22.3 *Bubble-sextant observations.* The normal type of accelerometer is not sufficiently sensitive to record accurately the lateral or longitudinal accelerations to enable the path of the aircraft to be plotted, but the bubble-sextant is a highly accurate and sensitive accelerometer—accelerations of the order of g/3,400 being detectable and measurable. With the recording sextant alone it is possible to determine whether the aircraft in controlled flight is a steady platform for bombing, for gun firing, or conducive to air-sickness. Thus, in 1940, one of our heavy bombers, previously believed from early stability measurements to be a fairly stable platform, was found from sextant records to show accelerations of

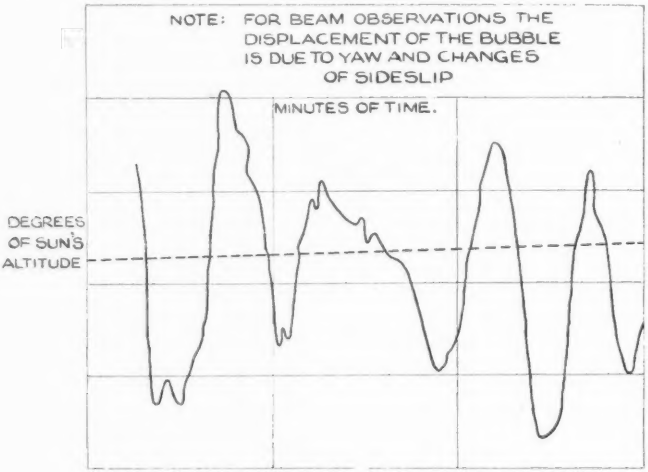

NOTE: FOR BEAM OBSERVATIONS THE DISPLACEMENT OF THE BUBBLE IS DUE TO YAW AND CHANGES OF SIDESLIP
MINUTES OF TIME.
DEGREES OF SUN'S ALTITUDE

FIG 13

BUBBLE SEXTANT ACCELERATION ERROR IN A HEAVY BOMBER WITH THE SUN ON THE BEAM

the order g/14, with a period of about a minute during manually controlled cruising flight. Records obtained from this aircraft from beam observations of the sun's altitude are shown in Fig. 13. These accelerations were traced to a slow roll and subsequent yaw, with an amplitude of about 5°. However, the sextant can only be used to detect a lack of steadiness but cannot by itself uniquely assign this unsteadiness to yaw, sideslip or changes of pitch. Clearly such an analysis is necessary if the flight characteristics of the aircraft are to be related to dihedral, fin area, surface sections, or any other design characteristic.

In order to provide such an analysis, the sextant records have recently been supplemented by observations of the sun with a pinhold camera in conjunction with records of the solar altitude (recording sextant) and A.S.I. Thus, from the correlation of pitch and A.S.I. readings and from the beam pinhole camera record, it is possible to determine the pitch, roll and yaw with a 50 per cent. error

of under 0.05°. A typical set of curves for a twin-engined medium bomber, known to be deficient in lateral stability, is given in Fig. 14.

This method of finding the flight characteristics is reasonably accurate and straightforward, but the computation work is too laborious for general application during the tests of prototype.

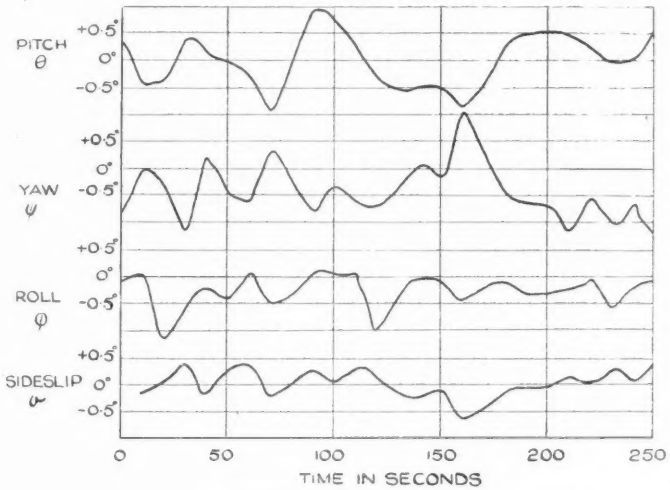


FIG 14.

CONTROLLED FLIGHT CHARACTERISTICS OF MEDIUM SIZED BOMBER AT MAXIMUM CRUISING SPEED

23. Behaviour with One or More Engines Cut.

The behaviour in the interval between the failure of any one engine and the resumption of steady flight, the power of the controls to permit subsequent steady flight and the ability of the trimmers to reduce the stick and rudder bar loads to zero, are determined for a variety of conditions and speeds. Though most of the tests will be made at the weight to which the full load can be reduced by jettisoning, at least one test in each series will be made at maximum weight.

23.1 *Interim period subsequent to sudden loss or increase of power.* All the tests under this heading are made with the propeller control set to the cruising r.p.m. or to the take-off r.p.m., whichever is appropriate. Caution is required during these tests since if the rudder hinge moment is likely to change sign, overbalance of the rudder may be experienced.

23.11 *Single-engined aircraft.* Tests to cover three cases are made. An engine may cut in the dive and it is necessary to determine whether the yaw and pitch are controllable. Secondly, the engine may fail during the transition stage during the take-off, that is, between take-off and best climbing speed, and it is required to know whether the change of longitudinal trim is manageable. Thirdly, a full throttle burst of engine may be required on landing. (See " Baulked Landing," para. 26.)

23.12 *Twin-engined aircraft.* This type of aircraft generally has the most critical behaviour of all types. The two most dangerous aspects are: An

engine cut during the transition stage of the take-off, and when a full power burst of the " live " engine is required during a landing with a " dead " engine. Tests are made to simulate these conditions at a safe height subsequent to similar tests at a higher speed. These tests provide valuable information on the directional and lateral stability of the type. For example, the rate of swing following an engine cut may be greater than the rate of roll, or vice-versa, and these rates of rotation are, to a large extent, controlled by the directional and lateral stability, coupled with the interaction of directional and lateral trim with slipstream. Tests are first made at cruising speed with each engine, in turn, throttled back slowly, followed by quicker engine cuts from higher and lower speeds. Again, two series of tests are made. In one series the pilot is invited not to control the aircraft until a roll of 45°, if necessary, is reached, and in the other he automatically corrects the rates of swing and roll as they develop, noting the stick and rudder bar loads (qualitatively) required to resume straight and level flight.

Since an engine cut may occur subsequent to the lowering of flaps and undercarriage, the tests are repeated with the aircraft in this condition.

In general, it is found that the rate of roll at the normal approach speed with flaps and undercarriage down, subsequent to a full throttle burst of power from one engine, causes an unmanageable rate of roll and swing, unless the aileron trimmer (if provided) and the rudder trimmer are set approximately halfway between the angle required for gliding flight and flight at the same speed with the live engine giving full power.

23.13 *Multi-engined aircraft.* The tests made on these types under the above heading are precisely the same as for twins, except that they are increased because the number of engines is doubled. The effect of cutting both engines on one side is also explored at cruising speed, but this test is not extended to high or low speeds.

23.2 *Steady motion flight with one or more engines cut.* Much handling information is automatically obtained during the partial climbs (para. 11.2) with one or more engines cut, but the handling at the speed for best performance obtained from these results is explored in greater detail, since this will be the speed most frequently used in level flight subsequent to engine failure. For four-engined aircraft the case of two engines cut on one side is considered. We measure the lowest speed at which the stick and rudder bar loads can be reduced to zero by the appropriate trimmers and since this speed is generally higher than the approach speed, or the speed during the transition phase of the take-off, tests are continued (*a*) to the speed at which the rudder and ailerons (if necessary) are at their limit stops, and (*b*) to the lowest speed for which there is sufficient control or until the control loads equal the pilot's strength.

All the above tests are made with the propeller control in low speed and some are repeated with the propeller feathered.

As mentioned in para. 11.2, a long flight on twins with one engine cut and on multi-engined aircraft with two engines cut, is made if the performance under these conditions is barely sufficient to prevent a rate of descent. Similarly, a long flight is made on twins with the propeller of the cut-engine feathered if the hand and foot load at the best speed for performance cannot be trimmed out. This is necessary since pilots are apt to describe these loads as light if a short flight only is made, but impossibly heavy if they have to maintain the load for a long period. On four-engined aircraft such a flight is made with the propeller of the outer cut engine feathered and with the propeller of the inner cut engine in coarse pitch.

24. Manœuvrability.

The normal manœuvres, involving the simultaneous use of the three controls, are assessed entirely from pilots' observations. It is not necessary here to detail

these manœuvres, though it should be noted that the bomber must be capable of taking useful evasive action at its cruising ceiling; F.A.A. types must answer well to all controls, particularly aileron, at low speed; the fighter must be easily rolled at high speed; the transport must be immune from high accelerations unless a sustained vigorous use is made of the controls, and Coastal Command types should instil confidence at sea level height.

The normal manœuvres are now augmented by quantitative tests of aileron (see para. 19.2) and of elevator. The latter are here described in some detail since they contribute valuable data relative to the safety of the aircraft, its stability at high speed and the c.g. range outside which general flying should not be permitted. These tests originated from work done by Mr. S. B. Gates, in which the potential value of the stick force per "g" as a criterion of manœuvrability in pitch, was discussed.

The stick force required to change speed from a given trimmed speed, the acceleration produced on releasing the stick from out-of-trim conditions, the stick force required to impose a given acceleration and the tendency to tighten in steady turns for different accelerations, are all measured. These tests can, of course, be applied throughout the speed range of the aircraft, but the first three are usually required only between top speed and the diving speed, since it is within this range that difficulties in the elevator control, stability, and in other features are most likely to be revealed. The tests are made at two heights on types with a high ceiling.

24.1 *Instruments required.* The following additional instruments are essential:—

(*a*) Desyn indicators for elevator and trimmer angle.
(*b*) Visual reading, maximum indicating accelerometer (for the pilot).
(*c*) Recording accelerometer.
(*d*) Stick force indicator.

An automatic observer should be used if possible to record the above data, together with A.S.I. and altimeter.

24.2 *Stick force in dive.* The aircraft is trimmed for full throttle in level flight and dived to various speeds up to the maximum permissible. It is important that the new speed be held long enough to stabilise before the readings of stick force, etc., are made.

For a rigid aircraft the stick force in out-of-trim dives is given by

$$P = mw\ S\eta\ c\ \eta \frac{b_2}{Va_2}(h - h_n^1)\left(\frac{V}{V_r^2} - 1\right)$$

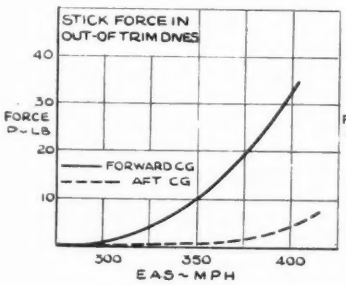


FIG 15

"CONVENTIONAL" AIRCRAFT (NO TAILPLANE DISTORTION)

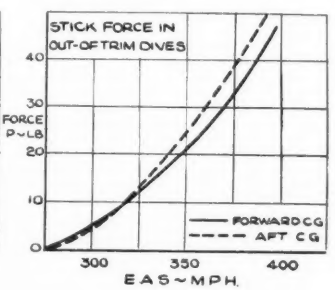


FIG 16

"CONVENTIONAL" AIRCRAFT (WITH TAILPLANE DISTORTION)

STICK FORCE AGAINST SPEED (EAS)

where V_T is the trimmed speed. The curves of stick force against speed will therefore be parabolic and show an increase of force for forward movement of c.g. Typical curves are given in Fig. 15 for the forward and aft limits of c.g. Should tail distortion, twist, etc., occur between the two speeds, the above relation does not hold. The curve of stick force against g will then be much steeper, and larger forces as the c.g. moves aft may be given due to loss of trimmer tab effectiveness at high speed. An actual pair of curves for such an aircraft of medium size is given in Fig. 16 for comparison with the more orthodox curves of Fig. 15.

24.3 *Acceleration produced on releasing the stick.* Following each of the tests at 24.2, the maximum acceleration following the release of the stick, starting at the lowest diving speed, is noted, together with other features which may be relevant, such as the change of attitude. These tests should be continued to the limiting speed or the speed which produces an acceleration of 5g on fighters and $2\frac{1}{2}$g on bombers or transports. A typical pair of curves (c.g. forward and aft) is given in Fig. 17 and the corresponding pair for the above aircraft in which the tail distorts is given in Fig. 18.

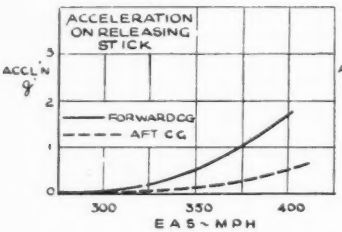


FIG 17

" CONVENTIONAL " AIRCRAFT (NO TAILPLANE DISTORTION)

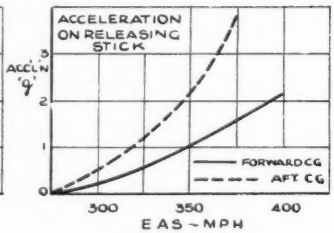


FIG 18

" CONVENTIONAL " AIRCRAFT (WITH TAILPLANE DISTORTION)

ACCELERATION ON RELEASING STICK AGAINST SPEED (E.A.S)

24.4 *Manœuvrability—stick force per " g."* The aircraft is trimmed into dives at various steady speeds up to the maximum permissible and recovery is effected by steady pulls on the stick. The pilot aims to impose an acceleration of 5g for fighters and $2\frac{1}{2}$g for bombers. The acceleration and the force are noted. Results have shown that different pilots produce varying forces in these tests until, by practice, they develop the same technique. For this reason tests made at different c.g. positions should be made by the same pilot and the whole repeated by another pilot. A typical pair of curves is given in Fig. 19, and a pair from the same aircraft noted above is given in Fig. 20.

24.5 *Steady tight turns (fighters only).* The aircraft is trimmed for a speed slightly in excess of twice the stalling speed, flaps up, and put into a 4g turn. The stick force to maintain this acceleration at constant speed is noted and the test repeated at other trimmed speeds up to the maximum level speed. The tests are continued as the c.g. is progressively moved aft and terminated when the behaviour in the turn becomes unacceptable, due to an excessive tendency to tighten up.

24.6 *Developments.* The results of the above tests indicate that certain peculiarities of the flight characteristics such as tail twist, or distortion, elevator heaviness at high speed, deficiency of stability and ballooning of the tail control

surfaces, can be revealed and by virtue of the quantitative measurements made, the importance of any feature can be graded. Automatic observers should be installed during the above tests in order to obtain precision in the results. In addition, provision for the measurement of tailplane twist and elevator deformations should be made in order to help in the identification of the feature responsible for unorthodox results. The skin deformation of supporting surfaces can be measured by a battery of electro magnetic micro coils, or micro Desyns.

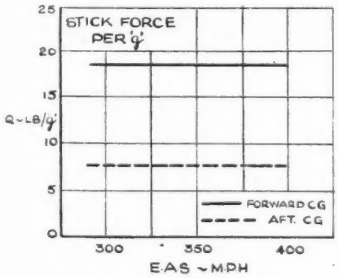


FIG 19

"CONVENTIONAL" AIRCRAFT (NO TAILPLANE DISTORTION)

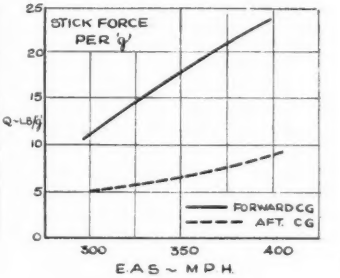


FIG 20

"CONVENTIONAL" AIRCRAFT (WITH TAILPLANE DISTORTION)

STICK FORCE PER 'q' AGAINST SPEED (E.A.S)

25. DIVES.

The tests under this heading are not to be confused with those of para. 24. These dives are made at any convenient c.g. position in gradual increments of speed to show up weaknesses in the design or structure, so that modifications can be quickly put in hand. Examples of the information required are:—

(*a*) Is difficulty likely to be experienced in the operation of the type under any of the many different conditions of the aircraft in which dives may be made when the type gets into service?

(*b*) Are there any structural weaknesses or defects such as loose cowling, insufficiently supported cupolas, Perspex blisters, faulty wireless masts, insufficiently rigid bomb or undercarriage doors, or any control instability?

(*c*) Do the propellers and constant speed units control the engine within the limitations imposed, irrespective of the manner in which the dive is started?

(*d*) Is the engine liable to cut during the early stages of the dive when a negative acceleration is applied?

(*e*) Are the emergency exits satisfactory?

(*f*) Is trouble likely to be experienced at high Mach Numbers and during bumpy atmospheric conditions?

It will be obvious that a large number of dives are required to cover adequately all the diving conditions likely to be encountered in operations and it is impossible to test for all of them. Some broad classifications, however, under which dives are organised to give the information required is set out below:—

(i) A series of straight dives is made at increasing speeds until the limiting design speed, limiting engine speed, or limiting speed due to any structure or

aerodynamic feature, is found. Information under (*b*), (*c*), (*d*) and (*e*) will be accumulated during this series.

(ii) A series of dives in which those facilities are used which are considered likely to cause major aerodynamic changes. Such facilities are:—

(*a*) Operation of bomb doors, and dive brake flaps, if fitted.

(*b*) Operation of each turret in turn at its maximum rotational speed, followed by simultaneous operation of all turrets. During these tests the pilot should pay particular attention to the behaviour of the controls. For example, it sometimes happens that the rotation of the nose or tail turret causes yawing oscillations and that rotation of the latter may cause the elevator or rudder to be moved due to a change in the local pressure field.

(*c*) Opening of clear view panels, side windows, sliding hoods, emergency escape doors, and the like.

(iii) Effect of yaw in the dive, both on flight characteristics and on the strength of component parts. The bomb doors should be operated both from the open and closed positions up to a speed within 50 m.p.h. of the limiting speed. They should be tested also in the open position up to the limiting speed for $\pm 10°$ indication on the bank indicator (this corresponds approximately to 10° sideslip). To determine the effect of yaw at high speed is most important since it is not uncommon to find that a pitching moment is introduced by the yawing, which may be difficult to control by the elevator. During these dives all controls will be tested for instability and self-centering properties. At least one dive will be made at the highest value of M consistent with the limiting speed (A.S.I.). A Mach meter should be fitted for this dive.

(iv) Out of trim dives. Large changes of lateral and directional trim with speed are bad features on fighters and dive bombers for obvious operational reasons. They are bad features for aerodynamic reasons on all types in which the controls are heavy. Consider the climb made through clouds in which the pilot is in trim about all axes at the best climbing speed. Should the blind flying instruments fail, a descent is likely, and, unless the pilot knows the trimmer settings corresponding to speed, he will either lose control or emerge from the clouds at a high speed with yaw and with one wing down. Experience has shown that a pilot is more conscious of a wing being down than he is of turning. Thus, on emerging from the clouds, he will try to lift the lower wing and in so doing, augment the yaw which in its turn will tend to depress further the same wing. If the controls are very heavy the aircraft may easily finish up out of control though the simple remedy of re-trimming the rudder would restore normality.

(v) Should any of the dives reveal compressibility features, an experimental series of tests will be required which necessitates precise measurements of control and trimmer angles, pitot pressure measurements close to the leading edge of the wing and/or tailplane and possibly measurements of pressure distribution over the lifting surfaces.

26. The Baulked Landing.

Like the one engine handling tests of twin and multi-engined aircraft, the baulked landing imposes very severe requirements of performance and handling. There are three critical cases to be explored:—

(i) With the aircraft loaded to its maximum weight with the c.g. in a position appropriate to this weight.

(ii) With the c.g. at the rearmost limit at a weight appropriate to this limit.

(iii) With the c.g. at the forward limit at a weight appropriate to this limit.

The normal landing technique with flaps down is made at each of the three above conditions. During the flattening out period the engines are opened to full throttle and the ability of the aircraft to effect a successful take-off is determined, first during simulated landings at a safe height, followed by actual landings, which are witnessed by ground observers. These tests are most instructive and contribute information on (*a*) the change of trim between no power and maximum power at a low speed, (*b*) the change of trim due to ground effect, (*c*) the power of the elevator to effect a three-point landing at the forward c.g. limit and its ability to correct for the change of trim at (*a*), (*d*) the pick-up and power of the engines to effect a successful climb away, (*e*) the " sink " (loss of height) and change of trim when the flaps are retracted to their take-off position, (*f*) the further " sink " and change of trim as flaps are raised to the fully-up position, and (*g*) the safe and best height at which the flaps can be raised to each of the conditions at (*e*) and (*f*).

Should a safe climb away be impracticable at any of the above loadings, the maximum weight and most forward position of c.g. at which a climb away can be made is determined.

27. Determination of Acceptable C.G. Limits.

The limits of c.g. within which an aircraft is safe for all forms of flying relative to the type cannot be deduced from any one set of tests. The pilot's general assessment is still the guide but the precise value is interpolated from the many quantitative measurements previously described.

27.1 *Acceptable aft limit.* The aftmost acceptable limit may, in war, be required for three different cases:—

(*a*) All the forms of flying expected of the type,
(*b*) Straight and level flight, and
(*c*) Special operations on a limited small number of aircraft.

The limit for conditions (*a*) is first proposed by the pilot. This limit is then considered in the light of the results of the quantitative tests at paras. 24.2, 24.3, 24.4 and 24.5 aided by the less precise, but nevertheless useful, data of paras. 18.1, 20 and 26. The limit for condition (*b*) is based primarily on the pilot's proposal, together with the data of 18.1, 20, 24.3 and 26. The pilot's opinion and tests 18.13 and 24.3 are generally used for the assessment under category (*c*).

27.2 *Acceptable forward limit.* The forward limit is more easily decided than the aft limit and it is seldom necessary to impose any restrictions on the flying manœuvres. It is applicable for all forms of flying and is assessed mainly from landing, taxying and the baulked landing, together with the results of tests at para. 24.

PART IV.

Miscellaneous Tests.

28. Cabin and Gun Heating.

It is essential in these tests to ensure that the cabin and gun cells are not preheated by the sun before flight. This is particularly necessary in summer because large metal parts, such as spars, etc., store a large amount of heat which will continue to be given out to the surrounding air for the maximum duration of flight and thus preclude the stabilisation of temperatures.

28.1 *Cabin heating.* Temperature measurements at the hands, feet and head position of the pilot, hands and feet of other crew and at all passenger stations may be required. In addition, the outside air temperature, the temperature and velocity of the heating air at all duct exits, should be measured so that the h.p. input can be calculated. For this purpose the mean velocity at the exits is taken as 0.8 and 0.7 times the velocity at the centre for circular and rectangular exits respectively.

With the heating " ON " the aircraft is climbed to within 2,000 ft. of its ceiling (at a light weight) where all heat is turned off and windows and other apertures opened for 15 minutes. The aircraft is then flown with heating " ON " at maximum cruising power with all windows and other apertures closed until the temperatures at all stations have stabilised for at least 10 minutes. As much of the Perspex roof as practicable should be curtained to reduce heat input from solar radiation to the minimum.

All the stabilised temperatures are then reduced by adding 0.75 ΔT where ΔT is the difference between the ambient air temperature and the standard sub-arctic temperature at the height considered.

28.2 *Gun heating.* The special electrical thermometric equipment shown in Fig. 21 is used since it is the gun temperature and not the gun cell temperature

FIG. 21.

Gun heating thermometer with various elements for different guns.

which is required. The internal temperature of the 0.30, 0.303 and 0.5" guns is measured by replacing the switch plate from the breech block by a replica switch plate containing the resistance element " *A* " (Fig. 21). Similarly, the firing pin and return spring guide and guide rod are removed from the 20 mm. gun and replaced by a replica unit with the resistance element in the top of the replica firing pin. A flush type element can also be used for measuring the external temperature of the gun. Thus the gun body and the switch plate temperatures can be related. The internal elements can then be replaced by the gun components and functioning trials made with the external element fitted. By this means the

internal temperatures at which the guns fail to function can be determined. The tests are made with gun muzzles, ejection and link chutes not sealed; where guns are fitted with rear sears they are tested with the breech blocks back; guns not so fitted are tested with the breech block forward and with a round in the chamber.

The thermometric equipment has eight elements, a junction box, control box and temperature indicator scale which can be balanced. Temperatures from $-60°C.$ to $+60°C.$ can be measured to $\pm 1°C.$ and the equipment is easily installed.

29. Cabin Contamination.

Tests are required to determine whether carbon monoxide from the engine exhausts is likely to enter the cabin under any flight condition. The conditions most favourable to the entrance of CO are: during the ground run up (windows, hood, or the like, open or closed), taxying, climb at full power and maximum power for continuous cruising in rich mixture (a half-hour test is usually sufficient) and in asymmetric flight of twin-engined types. The two most commonly used gas analysers are the R.A.E. Carbon Monoxide Indicator and the Mines Safety Appliance Co.'s indicator. These indicators are used by the A. & A.E.E. mainly during exploratory tests to determine where the concentrations are greatest. Samples of air are then collected in small rubber bladders at these places and analysed in the laboratory by the Palladium Chloride method.

Should the exhaust pipes be modified or engine cowlings altered, repeat tests will be necessary.

30. Noise.

At the present time, quantitative measurements of noise are only made when a complaint is made by any member of the crew. The object is then to identify the source of the major components of the noise; we therefore make a frequency analysis of the noise, usually at three stations—radio operator, a position near to the plane of the propellers and a crew station in the nose (where "aerodynamic" noise usually predominates). With certain exhaust systems, a further station in a plane aft of the exhaust exits may be tested.

Measurements are made by an objective noisemeter, augmented by an octave analyser, with mean frequencies covering the range 50-9,000 c.p.s. By comparing the frequency which gives the greatest intensity with the known rotational frequency, we can determine the main sources of the noise. Exploration of the fuselage with the analyser set to this frequency then indicates the place where the noise enters, whence it may be possible to produce an appreciable improvement by sealing gaps or by replacing thin transparent panels by thicker ones.

To complete the tests, a qualitative assessment is made. Each member of the crew reports on the noise at his station, including any vibration or rattles, squeaks, whistles, etc., which can produce annoyance out of proportion to their magnitude. If any such effects are found, they are traced to their source by ear.

31. Structure.

31.1 *Present tests.* Tests to determine the stresses in components and structure loads have not, in general, been made during prototype and first production testing except for measurements of:—

(*a*) Gun mounting stresses, which are determined on all types by electric strain gauge equipment,

(*b*) Blast pressures over the wing and body skin, occasioned by the firing of guns—measured by a battery of Piezo electro quartz gauges, and

(*c*) Maximum speed and acceleration in flight during 150 hours of intensive flying.

Much specialised research work has, however, been conducted as and when occasions arose or when information to assist in design was required.

The amplitude and frequencies of structure vibrations are measured by a battery of vibrographs but such measurements are only made if excessive vibration at any flight condition is reported.

31.2 *Developments.* Recent prototype test work has shown that certain measurements should always be made, otherwise wrong conclusions may result from a comparison of flight behaviour with model characteristics and derivatives determined by wind tunnel tests. For example, the static geometry will change in flight and measurements such as wing, body and tail flexing, wing, tailplane, and possibly fin, twist should be measured in order to obtain the relative settings of the various supporting surfaces. In large aircraft accelerations in the nose and tail, and at the engine bearers should be measured in flight, in take-off and landing, for comparison with similar measurements at the c.g. Similarly, strain gauges should be fitted to engine bearers for stress measurements subsequent to engine failure and possibly to other important components, such as wing spars (in the vicinity of the undercarriage attachments) and tailplane spar. The above proposals are made in respect of twin and multi-engined aircraft only. On fighters it may be necessary to fit instruments to determine whether there is distortion of the control surface contours during high speed dives and manœuvres.

There should be no need, however, to make elaborate provision for extensive strain gauge measurements, vibrations or pressures either at low or high values of M unless some feature of flight or design shows the need for an intensive exploration.

PART V.

Performance Reduction Methods.

32. Statement of the Problem.

Most of the quantities in performance tests are subject to corrections for instrument errors and those inherent errors due either to the inexactness of the method or because the location of the instrument precludes precise registration of the requisite quantity.

Even after corrections for the above have been made there remains the problem of plotting one quantity against another, both of which may be functions of the ambient air temperature at the pressure height at which they were measured. Thus it has been necessary to determine the law of variation of all the quantities concerned with air temperature so that they can be plotted to any given temperature-height curve. The I.C.A.N. temperature scale adopted many years ago is still the standard temperature to which all quantitative results, except engine cooling, are reduced.

The methods whereby the results are reduced to the I.C.A.N. scale have been deduced mainly from theoretical considerations supported by engine test bed data. Experimentally, they have been confirmed by the results of a series of flight tests made on a Spitfire (Merlin engine) in air temperatures varying between English winter (mild) and summer (fair). Further experimental results embracing a larger range of air temperatures have very recently been obtained from tests made in England and North Africa on a Lancaster Mk.I. We hope to extend this air temperature range still further by making repeat tests in Canada on the same aircraft.

33. Methods of Reduction.

The British performance reduction methods include the effect of changes of weight on speed and rate of climb, so that all results can be corrected to a common weight. In A. & A.E.E. reports all speed results are corrected to a standard weight equal to 95 per cent. of the take-off weight.

It is not necessary here to repeat the reduction methods, but there are some items upon which further information has been obtained since the issue of the report. These items, which concern the main assumptions made are:—

(*a*) The drag coefficient may be expressed in the form

$$C_D = C_{D_z} + C_L^2/e\ \pi\Delta$$

(*b*) The engine power varies with temperature at constant boost as $1/(T+127)$ on average for all engines. The supercharger compression ratio varies with temperature in accordance with the formula

$$ro = r\ (1 - C\ \Delta T).$$

(*c*) The variation of propeller efficiency during the reduction process can be allowed for at constant pressure by putting $(d\eta/\eta)/(dJ/J)$ equal to 0.2 in level flight or 0.5 on the climb.

(*d*) The engine power is given by $P+F$ proportional to $p(r-1/c)/(T+127)$.

(*e*) Engine cooling results.

33.1 *Drag law.* This will in general hold with sufficient accuracy for performance reduction purposes down to a speed $1.35\ V_{i\ mp}$ at least, except perhaps on bombers with high profile drag and high aspect ratio where C_L may be high at $1.35\ V_{i\ mp}$. Note that C_L at $1.35\ V_{i\ mp}$ is proportional to the square root of $(e\ A\ C_{D_z})$ and may be of the order of 0.8 on heavy bombers. In such cases, the $C_D - C_L^2$ curve may cease to be linear at high C_L. There is some indication of this from tests on a Lancaster with 30 per cent. weight change, where the current methods underestimated the effect of weight at low speeds.

This can be overcome only when a drag analysis has established the shape of the drag curve for the particular aircraft; it is not of great importance for the weight and temperature ranges used in normal performance reduction (note that no error occurs in reduction at full throttle for temperature changes when a height shift at constant V_i is used).

33.2 *Engine laws.* The constant of 127 in the above formula will vary with the engine charge temperature but until measurements of the charge temperatures are made on several aircraft, there is little we can do to qualify it.

With regard to the supercharger temperature coefficient (which affects boost plotting and all performance reduction at full throttle) the use of 0.002 for all engines is recommended unless there is evidence to the contrary. It has now been established that variations at least from 0.001 to 0.003 occur on current types, and A. & A.E.E. now divide all engines into three groups with constants of 0.001, 0.002 and 0.003 for the purpose of performance reduction; this grouping has been decided from tests in the case of Merlin, Griffon, Sabre, Hercules, Centaurus and Cheetah, and inspired guessing for all other British engines.

33.3 *Propeller laws.* The propeller laws given do not hold for high tip Mach Numbers though they appear to give reasonably satisfactory results up to the present. For precision work it would be necessary to make detailed calculations for each aircraft.

33.4 *Engine cooling results.* It is not usual to reduce engine and oil temperatures measured on test to the I.C.A.N. air temperature scale. In Britain they are reduced to one or other of two scales denoted by temperature of British summer and tropical summer. The present reduction methods are:—

(*a*) Cylinder and engine accessory temperatures. The correction to cylinder temperature is equal to the change in air temperature.

(*b*) Oil temperatures. The correction to oil temperature is equal to 70 per cent of the change in air temperature.

(*c*) Coolant temperature. The suitability of the radiator is evaluated by a formula which is equivalent to assuming that the change in coolant temperature is equal to the change in air temperature.

The method for cylinder temperature reduction is based partly on bench tests, partly on theory, and only to a very limited degree on experimental results. It

makes no distinction between climb and level flight, or between low and high speed level flight, although the change in mass air flow with temperature will be different in all these cases. Experimental confirmation (or otherwise) by tropical tests is urgently required. It now seems clear from cold tunnel tests of oil coolers, taking into consideration engine and aircraft characteristics, that no simple " percentage " correction can be true for all installations or even for a given installation at different parts of the air temperature range. Methods are therefore being developed in which mass airflow through the cooler, oil temperature drop, and air temperature rise are being measured for comparison with cold tunnel data.

The lack of reliable flight tests data on the effect of ambient air temperature on all engine cooling results is in marked contrast to our aerodynamic knowledge and much work needs doing in tropical and sub-arctic temperatures.

PART VI.

Developments in Prototype Testing.

34. The Future of the Test Pilot.

One of the salient features of a review of the tests and methods of the foregoing parts is that the test pilot still plays a large part (*a*) in the assessment of the behaviour of new types, and (*b*) in the accuracy of many of the performance results. Though his influence over (b) will become less, or, have a less important effect, his part in (*a*) will remain, and, since we can expect changes of design and many new flight problems, his part in the future may grow.

As explained in para. 16, the credit for the good behaviour of our present types is due mainly to the test pilot of the past and we can expect, therefore, that he will also play a large part in the development of the flight behaviour of future types.

If we are to keep up the present excellent all-round standard, it follows that the test pilot's knowledge and experience must advance apace with designers and as a first step towards ensuring this, a school for test pilots has been founded at the A. & A.E.E. The aircraft on which these pilots will be required to make certain tests will be fitted with the special instruments noted in the various " development " paragraphs of the preceding parts. A modern aircraft in which the area of the fin and the dihedral of wing tips could be varied in flight would be of immense help. By such provision, the interaction of lateral and directional stability could be studied in the only satisfactory manner, i.e. in flight.

35. Flight Testing Prototype Aircraft.

The advent of the Desyn system of remote indication of primary movement has greatly facilitated the problem of recording photographically on one film the three control forces and control angles. The time histories of many other quantities can likewise be recorded. Fortunately the transmitting unit of the Desyn system is of small bulk and the inertia of the control, or the like, to which it is fitted is not appreciably altered. Thus it is now practicable to equip even small aircraft with such recording instruments. Time histories of control forces and angles from the take-off to the landing (not necessary in all flights) will supply much badly needed information and eliminate many of the debates previously held between pilots and technicians. In addition, and on two counts, they will effect considerable reductions in the flight testing periods at contractors' works and experimental establishments; firstly by reducing the flying hours required by a given test pilot, and secondly by reducing the number of check flights by other test pilots. On the other hand, more technical and computing personnel will be required.

The advent of the electrical resistance strain gauge for the measurement of steady strains has been the same boon to stress analysis in flight as the Desyn indicator has been to control characteristics. Used in conjunction with the oscillograph, steady oscillatory and transient stresses are also readily measured by these gauges. Together with accelerometers and vibrographs they make practicable, stress measurements in flight, which hitherto could not be tackled in bulk form.

There are other instruments now available, such as the Brown Multiple Temperature Recorder, electrical equipment for identifying and recording vibration frequencies and radio recording of instrument values. The Brown Temperature Recorder, though bulky, would be extremely useful during performance and engine cooling tests, and cabin, turret and gun heating tests where high accuracy is of smaller moment than numberless readings. This recorder can cope with 144 different temperature units. At first glance this would appear unnecessarily many. On the other hand, we can in truth say that many more temperature measurements would, in the past, have been made had it been practicable to make them. For instance, on a four-engined air-cooled modern military aircraft there are 4×18 cylinders (the cylinder head and base temperatures should be measured on each); 4×4 oil temperatures and $(4 \times 6) + 1$ air temperatures; 4×6 engine accessory temperatures; 8-10 crew stations; 8-16 guns; a grand total of 230 odd. On large aircraft there is space and a definite requirement for such equipment. On small military aircraft the need is greater but the space available less, so that a more urgent requirement is temperature recording equipment similar to, but, say, half the linear dimensions of the Brown recorder.

Single-seat fighter aircraft have already exceeded the rate of climb at which a pilot can write down height against time with sufficient legibility and accuracy to enable the rate of climb curve below the full throttle height in high speed supercharger to be constructed. Automatic observers for all climb tests are therefore a necessity on such aircraft. Likewise, automatic observers are now needed for engine cooling tests. It follows, therefore, that speed measurements and engine cooling tests in level flight will also be recorded by the same apparatus.

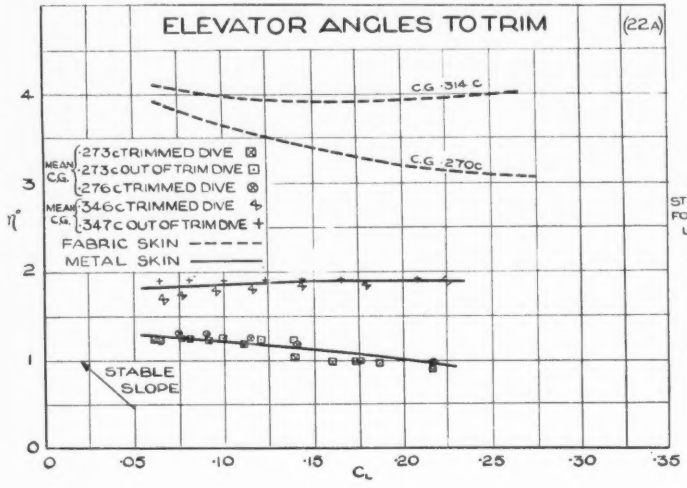
One might, with reason, argue that if it has only recently become necessary to equip fighters with automatic observers on the score of high rate of climb, then the large aircraft would not require such equipment for some considerable time. This finding would, however, not receive support from anyone with direct association with the flight testing of aircraft during the last four years unless it was qualified by the statement that further tests to determine the effect of alterations in the external shape or in the engine and its accessories would *not* take place.

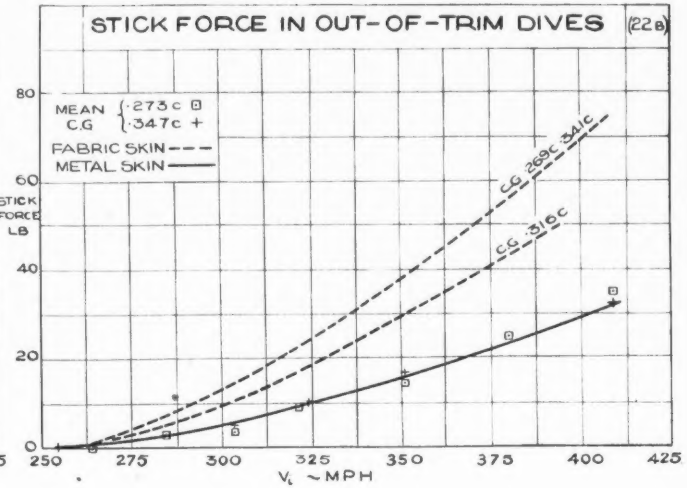
Excepting the perfect prototype, which is no different in production, various items on which the performance depends are changed during the flight testing periods at firms and experimental establishments. Hence every set of performance results should be obtained with the greatest precision possible, otherwise much inconclusive data and incorrect decisions may follow each subsequent series of tests. Also, there is the question of pilotage. Unless a pilot makes speed measurements strictly in accordance with the technique stated in para. 9.1, further errors in speed measurements occur. On single-seat aircraft we have no check on this, but in multi-seat types where a technical observer is carried, non-adherence to this technique can be checked. Again, much of the present abortive test work and lack of confidence in results would be eliminated if torquemeters were fitted.

Apart from the question of accuracy, the automatic registration of all relevant results (including engine B.H.P.) of performance tests will:—

(1) Reduce the flight testing period by eliminating repeat tests;

(2) Help the technician to distinguish and discard, without reduction, those results which are unreliable on account of bad weather or bad piloting;


ELEVATOR ANGLES TO TRIM
(22A)
C.G. 314 C
C.G. 270c
MEAN C.G. {·273c TRIMMED DIVE
·273c OUT OF TRIM DIVE
·276c TRIMMED DIVE
MEAN C.G. {·346c TRIMMED DIVE
·347c OUT OF TRIM DIVE
FABRIC SKIN
METAL SKIN
STABLE SLOPE
η°
0
1
2
3
4
0
·05
·10
·15
·20
·25
·30
·35
C_L


STICK FORCE IN OUT-OF-TRIM DIVES
(22B)
MEAN C.G {·273c
·347c
FABRIC SKIN
METAL SKIN
C.G. 269c
C.G. 341c
C.G. 316c
STICK FORCE LB
0
20
40
60
80
250
275
300
325
350
375
400
425
V_i ~ MPH

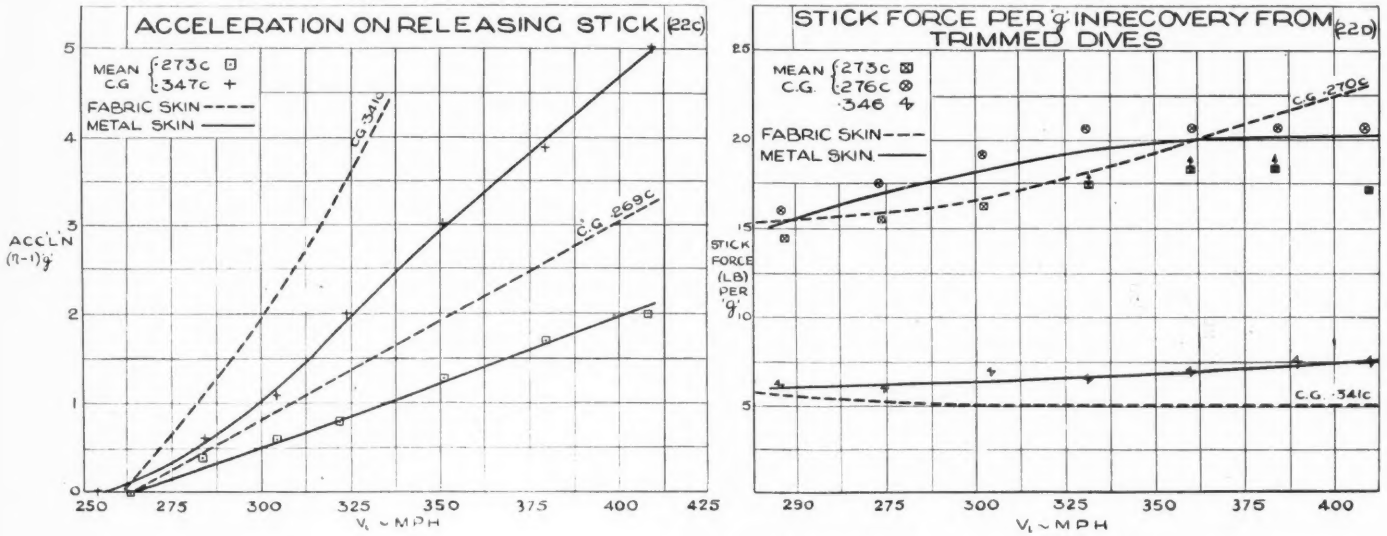


FIG 22 (A,B,C,D)

A SET OF CURVES SHOWING THE VALUE OF QUANTITATIVE MEASUREMENTS OF ELEVATOR CHARACTERISTICS

(3) Help in promoting good piloting and increase the confidence of all concerned in the derived curves;

(4) Provide records which can be re-investigated should questionable data be reported; and

(5) Ensure that a series of tests to determine the effect of, say, changes of intake, carburettor, propeller, limiting boost and/or engine r.p.m., cooling systems, etc., yield accurate conclusions even though power fading or engine replacements have taken place during the period.

With reference to performance tests on multi-engined aircraft, the late Mr. Edmund T. Allen, in the Sixth Wright Brothers Lecture, presented before the Institute of Aeronautical Sciences, states, " It is highly desirable, in fact almost essential, that simultaneous readings of power conditions, air speed, and altitude be taken if satisfactory data are to be obtained."

Turning now to the methods given in Part III for determining the flight behaviour we find that many quantitative tests are made which require special instruments. Even though visual types have mainly been used, these tests have quickly merited their inclusion in the test programme because (*a*) they give value to the pilots' findings and (*b*) they help in tracing to the source faulty behaviour. An example under (*a*) is in the determination of the safe or acceptable c.g. limits for all forms of flying (para. 27). An example under (*b*) is best illustrated by Figs. 22 to 22d, which show some comparative curves from a modern aircraft fitted, in turn, with fabric and metal covered elevators (the elevator shape and rib spacing were constant).

The broken lines (fabric) of Fig 22a indicate, by their tendency to curl up at the high speed end, that some distortion of the tail surfaces is taking place, while Fig. 22b shows that at the forward limit of c.g. the stick force required to dive when trimmed for full throttle in level flght is too high (for the class of aircraft). In addition, Fig. 22c shows that at the rear limit of c.g. the acceleration on releasing the stick is too high.

Compare now the full lines (metal skin) with the broken lines (fabric skin) of the same figures, and a rather surprising, but satisfying, difference will be observed. Fig. 22d, where there is little change, shows the stick force per " *g* " to recover from trimmed dives.

The moral for emphasis is not so much that a stiffer skin than fabric was desirable, but that the flight test results themselves indicated the treatment to apply. Without such measurements the pilots' findings cannot be truly related and finality of design is delayed.

The actual points have been plotted in Fig. 22 to show the order of consistency obtained from visual reading instruments by the same pilot. Different pilots do not get the same absolute results (excepting, of course, the steady motion tests of Fig. 22a) though the relative positioning of a set of curves is sensibly the same. These results are of such obvious value that the replacement of visual instruments by recording instruments is an unquestionable development.

36. Automatic Recording of Instrument Values.

Opinion is unanimous that it is better to plan the flight test programme while the prototype is being made, rather than fit in what tests one can after it has made a preliminary handling flight. It is still a moot point, however, whether it is advisable to equip each, or any prototype, with all the recording instruments to cope simultaneously with (*a*) aircraft engine performance tests, (*b*) tests to investigate flight characteristics, and (*c*) tests to determine structural stresses, robustness and vibration nodes and all the sundry other tests not easily classified. The larger the aircraft the greater is the necessity to consider the probable duration of the flight test period and to plan for this to be a minimum. It can be shown that recording instruments for tests under each of the broad classifications (*a*), (*b*) and (*c*) reduce the amount of flying time required in each, and though there

is bound to be an economical limit to the total number of recording instruments, there would appear to be no over-riding reason why the three sets of instruments should not be carried simultaneously if there is sufficient space to accommodate them. On the other hand, there are many occasions during the flight test period where there would appear to be over-riding reasons for their simultaneous inclusion. For example, all flight test work must proceed in gradual stages. Thus light load is gradually increased to maximum load, medium speed is gradually increased to top speed and thence to the limiting diving speed, and from low altitude tests the characteristics at the ceiling are explored. This is precisely the process required during each of the set tests (*a*), (*b*) and (*c*). Hence information on all subjects can be gathered in a planned process and correlated by the ground staff as the flying hours build. By the time the aircraft has been tested at the stall and at its limiting diving speed from maximum weight, and at the ceiling at its light weight, much of the requisite data on performance, stability, controls and strength will be available.

Should it be decided to fit instruments for (*a*) only, there will be a tendency to concentrate on performance and as this involves much flying at full power, there is the danger of early engine replacements. Similarly, if special instruments for investigating control and stability only are fitted, some time may elapse before it is revealed that the air intakes are inefficient or the landing stresses in some particular member of the undercarriage are too high.

The influence of weather and the unserviceability of prototypes are relevant factors in any estimation of the flight testing period, but they do not enter into this discussion except indirectly. On average and all the year round the prototype in its early life may fly only one day in three. The more information we can get from each flying day the quicker the stages are reached when (*a*) rough weather is no longer a deterrent, and (*b*) when light load can be replaced by full load. It is opportune here to make three important observations:—

(1) From the " skipper's " point of view more information is gained from one hour's flying in rough weather (not merely bumpy, as occasioned by heat or ground topography) than from 20 hours calm weather flying, making quantitative stability and control tests.

(2) From the operator's point of view a modicum of accuracy and a few results of the performance at full load are worth more than precision and a wealth of results at the weight at which on operations the aircraft will be preparing to land.

(3) From the engineer's point of view the reliability of the engineering of the aircraft as a whole, and its ease of operation in sub-arctic and tropical climates are of much greater value than forecasts and reduced results from tests made in a temperate atmosphere.

Though irrelevant to the heading of this paragraph, the three statements above are necessary as a leveller of test values. Such a leveller is important when it is recalled that none of the many tests of electrics, hydraulics or general engineering services has been mentioned. It is obvious that information on the functioning and reliability of all facilities and services should be accumulated steadily throughout the flight test period and that the programme of tests must be progressed on broad lines.

Before ending this interesting subject, there are two papers of the Aeronautical Journal to which special reference should be made. The April-June copy of 1917 contains the paper " Methods of measuring aircraft performances," by Capt. H. T. Tizard, and the following is a quotation, " Get careful flyers whose judgment and reliability you can trust and your task is comparatively easy; get careless flyers and it is impossible." Those statements are just as applicable to-day and it should not be thought that a lower standard of pilot can be accepted if a high degree of instrumentation is planned.

The second is a paper (1930) on "Testing aeroplane controls," by H. L. Stevens. This paper strongly advocates the development of instruments for the measurement of control forces and angles.

37. Concluding Remarks.

It can be stated that the flight testing of prototype and first production aircraft is to-day a more important period in the history of a type than it has ever been and that more attention should be given to it than in the past.

The pilot, technician and research worker have between them progressed well in the methods of flight testing. Instrument makers and radio workers have also forged ahead. Thus, while the need for reducing the flight testing period of new types is great, the means of achieving a reduction are available. In addition, the automatic registration of instrument values will augment accuracy and lead to the accumulation of much more reliable data than has hitherto been practicable.

First in importance is the planning of the flight tests. This should be commenced as soon as the decision to make the prototype has been made. Secondly, all those instruments necessary for the complete schedule of tests should, if practicable, be fitted in the first prototype. If two or more are being made concurrently, then it may be preferable to fit all the distortion and stress measuring instruments in the second and omit them from the first. The layout of instruments and the flight schedule should be arranged so that advantage can be taken of the weather conditions for making specific tests. In particular, an easy and quick method of loading large aircraft should be provided, with means for disposing some of this load for landing.

To complete the test programme of long range aircraft, tropical and sub-arctic testing stations are now necessary developments, though such tests may be more suitably made on an early production aircraft.

38. Acknowledgments.

The author is one member of a team of pilots, technicians, engineers, physicists and research workers, all of whom, by virtue of their normal work and investigations, have contributed to this paper.

APPENDIX I.

Air Temperature Measurement in Flight.

1. Requirements.

As stated in para. 4, we require a method of measuring the ambient air temperature from the aircraft while performance measurements are being made. The accuracy of the instrument should be within $\pm\frac{1}{2}$°C. and in addition it should comply with the following conditions:—

(*a*) The transmitting unit must be clear of the propeller slipstream, which generally contains heated air from the engine, and it must not be affected by solar radiation or reflected radiation from the tops of clouds.

(*b*) The receiving unit must register faithfully the temperature at the transmitting unit. Hence the receiver must be insensitive to the cabin temperature and the capillary, wires, or the like, between the two units, must be insensitive to the temperature of their surroundings.

(*c*) The fitted thermometer must not interfere with the air flow over supporting surfaces and its drag must be negligibly small.

(*d*) The instrument should register temperatures between -70°C. and $+30$°C. and the receiving unit should, if practicable, be readily convertible from visual reading to recording.

2. Development of Thermometers.

2.1 *Capillary type transmitting thermometers.* The mercury type is limited to temperatures of $-35°C.$—the freezing point of mercury. The nitrogen type extends the range to $-60°C.$ but the nitrogen tends to leak with time and thus its calibration must frequently be checked. Further disadvantages common to all variants of this type lie in transit, storage, installation and repair.

2.2 *Cambridge electrical transmitting thermometer.* This instrument has been used extensively on the two meteorological aircraft referred to in para. 4.1, and, on the whole they have been fairly satisfactory. The transmitting element consists of a platinum wire inside a copper spiral. The terminals of the element connect with a control box in the cockpit, which is virtually and unbalanced Wheatstone bridge. The out-of-balance current is read on a suitable indicator graduated in temperature. The control box contains compensation for leads and battery voltage. The flat dial version of the instrument is accurate to $\pm\frac{1}{2}°C.$, has no appreciable lag, and, except for the indicator, is robust. However, the instrument and layout are fairly complicated and the indicator too sensitive to acceleration.

2.3 *Multi-junction thermocouple type.* During flight tests at the A. & A.E.E. of an N.P.L. design of hygrometer, the necessity for measuring air temperature more accurately became acute and a thermometer, to read $\pm 1/10°C.$, was developed jointly by the N.P.L. and A. & A.E.E. This instrument consists of 6 copper-constantin thermocouples in series, with one set of junctions exposed to the free air stream (mounted in a slightly ventilated pitot fairing) and the other set immersed in a thermos flask of melting ice, situated in the cabin. The thermo-electric current produced is measured by a micro-ammetor and converted to temperature.

Though highly accurate and suitable for its design purpose, this thermometer is not readily adaptable for the purpose now considered.

2.4 *New type electrical thermometer.* This thermometer has recently been developed at the A. & A.E.E. by Mr. Brewer, of the Meteorological Office, and has an accuracy well within the prescribed $\pm\frac{1}{2}°C.$

A batch of these thermometers is now being made and we at the A. & A.E.E. intend to fit each aircraft under test with its own thermometer and so replace gradually our present method.

3. Calibration of Fitted Thermometer.

After the normal ground calibration subsequent to installation, the instrument will be calibrated in flight during the tests described in para. 5, to determine the overall effect in flight of:—

(*a*) Errors due to its position and installation, and
(*b*) The compression heating error.

4. Compression Heating Error.

This error is caused by the conversion of the kinetic energy of that part of the air striking the transmitting element into heat energy and thus raising the temperature of the element above that of the ambient air. This energy conversion is made in a combination of two ways, (*a*) by adiabatic compression (or nearly so) of the air at the stagnation part, and (*b*) by skin frictional heating of the air flowing over the sides of the element. The relative contribution of effects (*a*) and (*b*) is dependent upon the design of the element, a thermocouple facing forward being entirely (*a*) and a flat plate mounted edgewise almost entirely (*b*). By relating the kinetic energy of unit mass of air to the heat rise that is

$$\left(\frac{V^2}{2gJc}\right) = C_p \Delta T$$

the theoretical adiabatic temperature rise ΔT for an element of type (*a*) can be shown to be

$$\left(\frac{V \text{ m.p.h.}}{100}\right)^2$$

degrees centigrade approximately.

Thus an external thermometer with such an element on an aircraft travelling at 300 m.p.h. will over-read the ambient air temperature by 9°C. if its sensitive element is fully exposed to the air stream. The skin frictional heating effect cannot be expressed so simply, but on average is proportional to about $V^{1.7}$. In practice, therefore, the full adiabatic correction may not be realised but experiments have shown that it can be obtained by careful design of the sensitive element and a suitable fairing, and the fairing ensures that the correction, though large, is both accurate and consistent.

The multi-junction thermocouple pattern of thermometer has its sensitive element in a pitot fairing for this reason, and a later modification to the balanced bridge instrument has utilised a similar principle.

APPENDIX II.

Design Features of A. & A.E.E. F.47 Take-off Camera.

1. Introduction.

The F.47 camera, manufactured by Messrs. W. Vinten, Ltd., to an A. & A.E.E. specification, has been in use now for four years, during which time much experience of its adaptability has been obtained. Some improvements have been incorporated and it is desirable, therefore, to give a very brief description of the present variant of the model and to refer to probable developments.

2. Description (see Figs. 2 and 3).

The camera is virtually a phototheodolite mounted on a gyro-head in a hemispherical bowl. The feet of the supporting tripod are provided with large area pads to provide rigidity when set up on grass. The camera can be levelled by means of the screws "*A*" and the cross levels "*B*" (Fig. 2). When levelled, the gyro-head is clamped into position by the friction clamp "*C*." The camera can then be rotated about a vertical axis through 360°. It is operated by the left hand through the control arm "*D*" (Fig. 3), the right eye to the eye-piece, and the right hand resting upon the camera. The gyro-head mounting ensures a smooth rotation of the camera and enables the operator to keep the aircraft in the centre of the field of view.

Seventy mm. film with standard 35 mm. film perforation is used and the picture size is $2\frac{3}{4}'' \times 2\frac{3}{8}''$. Provision is made for loading $2 \times 200'$ lengths of film and a footage counter "*E*" is provided, together with a Veeder counter, photographed by the film, which automatically registers after each run. There is a glass graticule in front of the film at the vertical plane and on this are engraved horizontal and vertical datum lines which pass through the principal point of the lens. This is ensured by determining the principal point of the lens photographically after the graticule has been located in the gate, the datum lines being engraved after the resultant film is analysed.

The shutter is of the rotating type with a sector shaped aperture of variable width. The speed is variable with a maximum of 80 frames a minute, and the time of exposure from 0.01 to 0.02 second. A 20″ telephoto lens is fitted and the camera is driven by an electric motor "*F*" from a 12-volt supply.

The switch "*G*" is first turned on and the motor started after the camera has been sighted on the aircraft. This sets only the shutter in motion, the rest of the mechanism being set in operation at the appropriate time by means of the clutch lever "*H*." When the camera comes to rest after filming the aircraft it automatically leaves an unexposed piece of film in the gate so that the first

exposure on the next operation occurs immediately the clutch is switched over.

The watch " *I* " is conveniently placed so that it can be wound, started and stopped without removing it from the camera.

Each exposure on the film, two frames of which are shown in Fig. 4, shows :—

(i) An image of the aeroplane, together with a horizontal and vertical line to act as a datum for measurements.
(ii) The azimuth bearing of the camera with reference to a fixed datum.
(iii) A hundredth second watch, and
(iv) An identifying number to fix each run.

Further Developments.

The F.47 camera has proved to be a most successful instrument for filming the take-off and landing of aircraft, but provision will be made for increasing the film speed to give 4-6 frames per second. This speed is considered to be fast enough for all take-offs except those forming part of a series of research experiments, where a much higher speed, possibly up to 30 pictures per second (as adopted in the N.A.C.A. phototheodolite) may be necessary.

APPENDIX III.

Additional Engine Cooling Tests to Those Previously Standardized.

The maximum power ratings of certain engines has increased of late without a corresponding increase in the limitations for weak mixture. This has resulted in a wide difference between the full throttle heights for all-out level and for maximum weak mixture cruising powers. To take account of this the following tests have been added to the A. & A.E.E. cooling test programme.

1. Tests in High Speed Supercharger.

1.1 Level flight run (for 20 minutes or until stabilised) at maximum r.p.m. and boost for continuous weak mixture cruising and at the observed full throttle height for these engine conditions, with gills closed. If the aircraft cannot cruise at this height, the test is to be made at a height (rounded off to the nearest 1,000 ft.) approximately 1,000 ft. below the cruising ceiling. Unless it is certain that the cooling is adequate for the required standard temperature conditions, this test is then to be repeated during the same flight at a number of increased gill openings sufficient to establish the effect of gill opening on both cooling and performance.

On liquid cooling installations, for " gill " read " radiator flap."

1.2 Level flight run (for 20 minutes or until stabilised) at maximum r.p.m. and boost for rich mixture cruising conditions and at the observed full throttle height for those engine conditions, gills closed.

1.3 At the full throttle height for all-out level power conditions, a 10 minute run at maximum r.p.m. and boost for rich mixture cruising, followed by a five minute run at all-out power.

2. Tests in Low Speed Supercharger Gear.

2.1 At that engine condition (weak mixture cruising or rich mixture cruising) which gives the lower cooling suitability, the corresponding test is to be made; both cylinder (or coolant) and oil temperatures are to be considered, since they may reach their highest values at different power conditions.

2.2 The test of 2.1 is to be repeated at the lowest practicable altitude on liquid and air-cooled types.

Note.—In any installation where the full throttle heights for different power conditions do not differ by more than about 1,000 ft., it will suffice for the tests to be made at a single intermediate height.

The normal climb test will be made, but, in addition, a further climb test will also be made on any aircraft which is capable of climbing at maximum weak mixture cruising power. A climb to Service ceiling (for this power condition) will be made at maximum weak mixture cruising power and at an airspeed (varying with height) approximately half-way between best climbing speed and the level speed for this power condition. Gills (or radiator flap) will be about half open for this test, a repeat being made with a different opening if the cooling is inadequate or excessive.

DEFINITION OF SYMBOLS.

M—Mach Number $= V/a$.
V—True air speed.
a—Velocity of sound in air.
V_i—Equivalent air speed.
V_r—Reading of air speed indicator corrected for instrument error.
σ—Relative air density, i.e. ρ/ρ_o.
$V_{i\ mp}$—V_i for minimum thrust power required, in level flight (i.e. minimum drag power).
p—Relative pressure.
η—Elevator angle or propeller efficiency.
β—Elevator trimmer angle.
C_L—Lift coefficient.
V_T—Trimmed speed.
m—Elevator stick gearing, radians per foot.
w—Wing loading.
$S\eta$—Elevator area.
$c\eta$—Elevator mean chord.
a_2—Rate of change of tailplane lift coefficient with elevator angle.
b_2—Rate of change of elevator hinge moment with elevator angle.
$\overline{V}$—Tail volume.
$(h'n—h)$—Static margin stick free.
J_e—Joules equivalent.
g—Acceleration of gravity.
C_p—Specific heat (air) at constant pressure.
c—$C_L^2/\pi Ax$ induced drag coefficient.
T—Air temperature in degrees absolute.
J—Propeller coefficient $= V/nD$.
C_{Di}—Drag coefficient extrapolated to zero lift as straight line against C_L^2.
A—Aspect ratio.
r—Supercharger compression ratio.
r_o—Value of r at 15°C.
C—Constant defining the variation of r with temperature.

During the reading of the paper, three short cinematograph films were shown. The first showed rudder and elevator movement during side slip; the second showed the " shimmying " of the tail wheel of an aircraft when landing, which was overcome by the fitting of a twin-contact tyre; and the third depicted the dropping of a sea rescue boat from the air by parachutes.

Discussion.

Group Captain Bulman (*Fellow*): The lecture constituted a complete story, and it would remain a classic for many years to come, as had the papers by Tizard (1917) and by Stevens (1930).

The lecture was not only a comprehensive and detailed list of the tests which the experience of many years had proved to be necessary and the methods of

carrying them out but also was of value to those on whom was laid the responsibility of drawing up new specifications. The relationship between the specification and the test schedule is apparent to all concerned with the latter and it is in this respect that the results of flight test work can be most constructive. To those whose duty it is to deal with reports of flight tests it is axiomatic that many qualities or deficiencies in aircraft are the result of the initial conception or specification, are frequently unalterable without major re-design and the lessons to be derived therefrom can only be applied in the future.

At the same time he was sure that the author would be the last to suggest that the scope of his paper included more than the final testing of the ideal aircraft. A tremendous field of development work, aimed at improvement in performance and reliability of the airframe, power plant and equipment, involved continuous search for new methods of testing.

The approach to the testing problem by such development engineers was different in that the object was more often constructive or ad hoc and tests were felt to be more under control in wind tunnels or test beds. Often time was saved by these methods and flight tests were only used as a final check on the reproduction of air tests on the ground.

The author had paid a very nice tribute to the work of the test pilots; the test pilots appreciated that, just as they appreciated the co-operation and help they received from the officers of the testing establishments and from their own technicians.

The importance of team work had quite rightly been stressed in the paper; the team, consisting of scientists and the designer, the technicians and the test pilot, must work efficiently if the proper results were to be obtained. It was true that by instrumentation one could achieve or accept the technical side of the control of test flying. There was, however, the other aspect, that where the technician or engineer was himself a pilot he might be able to point to many short cuts which helped in the analysis of troubles.

A little while ago it had seemed apparent that test flying was becoming more and more a science; and one tended to look forward to the time when the majority of the tests could be carried out before flight, *i.e.*, on the ground and in the wind tunnel. But the developments in aerodynamics and performance generally had been such that in his opinion test flying was still just as much an art, and was probably likely to remain just as much an art, as ever it had been.

Although the paper had hardly dealt with the human side of the development work, it was worthy of some discussion. Test pilots were accustomed to say, among themselves, that to get the right answer and to know what to do represented only 20 per cent. of the work. The other 80 per cent. consisted of trying to put it over and to tell others what they thought was the right thing.

The assimilation of such a compendium of flight tests as was represented by the paper required a wide knowledge of aircraft and of fundamental physics; and those who were not yet convinced of the necessity for a technical training college or of the provision of the maximum training facilities for all who worked in the industry would do well to read it and try to reproduce it themselves.

Finally, Group Captain Bulman expressed gratitude to the author for the enormous amount of trouble he must have taken to prepare the paper; he would be rewarded by the knowledge that his paper would be of very great value to many people for many years to come.

Mr. R. K. Pierson (*Fellow*): He agreed that before the cooling tests it was essential that carburation tests should be carried out at C/B and R.B. Unfortunately, only the electric propellers were at present arranged so that their pitch could be fixed, and the drop in revolutions could not be determined at maximum cruising revolutions. Therefore, he asked if it would be possible for the manufacturers of hydraulic propellers to make a gadget which would fix the

coarse pitch to give approximately the correct cruising revolutions with maximum weak-mixture power.

Coming to performance and control with one or more engines "dead," Mr. Pierson said that those conditions presented big problems to the designer of the heavily loaded bomber. Tests were called for under the most adverse conditions, with cooling aids, gills, shutters, etc., opened to their maximum on the "live" engines. The cooling aids often had such adverse effects on performance that the loss of speed more than counteracted the increased cooling. That would be most apparent under tropical conditions, where the I.A.S. was low and the drag effect on speed was large. It was felt that predictions of tropical performances from tests made in this country would not always give the true picture.

With regard to cooling tests on engine installations, he said cases had arisen where the present method of testing the suitability of oil coolers had proved the installation to be satisfactory, but trouble had been experienced with over-cooling when in service under economical cruising conditions. Thus, it was necessary to stress that more attention should be paid to the operational conditions under which the aircraft would function eventually.

Cabin heating tests should be made at or near the operational altitude rather than near the ceiling, so that engine powers and mass flow of heating air was more representative of conditions in service. It was also essential to make a second test under economical cruising conditions.

Finally, Mr. Pierson endorsed Mr. Jones' remarks concerning the pilots, for the pilots represented the final answer in every case.

Group Captain McKenna (*Fellow*): He was particularly appreciative of the opportunity of hearing the paper presented, for he had recently arrived back in this country from America, having been away for 2½ years. Before that period he had had the pleasure of working with Mr. Jones for a number of years at the A. and A.E.E.; he was glad to acknowledge that the technical staff there had assisted and co-operated with the pilots to the utmost extent, and to express gratitude for that help. At the same time, it was pleasing to hear Mr. Jones' tribute to the pilots.

The changes which had been effected in flight testing methods in the relatively short time during which he had been away were most impressive. Those methods had become much more scientific than formerly, particularly in the increased use of recording instruments; a technique which has been highly developed in America. It was interesting to compare the progress which had been made in this direction in the two countries. The paper would be of very great value indeed to almost everyone connected with aeronautics.

Sir Frederick Handley Page (*Fellow*): He was concerned with the time occupied by, and the cost of, the test flights of new machines. In the first place, he wondered how far it was possible to achieve a better organisation of test flying by reason of the improved navigational facilities available, by having more navigators taking part in the testing of a large machine, by more wireless facilities, and so forth, so that more testing could be compressed into a shorter time than had been the case hitherto.

At present, he said, when a new prototype came out, everybody in the works at which it was produced became very "het up" about it and were anxious that it should take the air as soon as possible. It would be ready on the specified day, and then perhaps it would fly for the first time. After that, very often, there was a period of quiescence, during which the designers of the aircraft waited with bated breath for the next flying results. Then perhaps the weather was unfavourable; there were clouds when there should not be clouds! On the other hand, if the weather were fine, perhaps something would go wrong with the engines! All sorts of things happened to prolong something which was of vital importance to the future of the prototype. One wondered whether the

importance of completing the test flying within a short time was really understood and appreciated by everybody concerned; and whether, if more money were spent in the organisation of the testing of aircraft in order to complete the tests within a short time, they would not achieve very much better results. Sir Frederick asked whether Mr. Jones and his colleagues at Boscombe Down had considered the possibility of flying much more frequently if more navigational and wireless facilities, and so on, were placed at their disposal.

With regard to the actual measurement of the various factors which had to be measured in the course of a test flight, perhaps some speeding-up could be effected. At present quite a number of observers took part in the tests, and perhaps one of them would become ill on the day he was required to make observations. That was another reason for putting off a flight test! Would it not be possible, by the use of more automatic recording instruments or by taking more readings by means of a cine-camera or some instrument of that kind, for the pilot alone to take the machine into the air and to obtain the information that was required? The pilot could then level out at the various heights at which readings were taken, and when he pressed the appropriate buttons he would know that automatically everything was happening at the back. By pressing button A he would record the speed of level flight. By pressing button B he would not get his money back, but he would record some other factor which had to be measured.

The cost of the delays in carrying out test flying as at present was considerable. But the necessity for avoiding delays became even more important in connection with civil flying, because in that case the customer was perhaps not so open-handed as the Government, which was concerned with military types of aircraft. The buyers of civil aircraft did not necessarily consider that a very high degree of accurate testing on the aircraft was essential. They wanted aeroplanes which would carry a given number of passengers a given distance within a given time, and it was for the contractor to ensure that the aeroplanes were capable of giving that service.

Sir Frederick asked whether Mr. Jones had in mind any new plan for the development of Boscombe Down whereby machines would be leaving the ground every five or ten minutes throughout the day and night, and automatic calculators would be used so that results could be handed out " five miles an hour " faster than could be done otherwise.

Flight Lieutenant C. F. UWINS (*Fellow*) commented that the description of the tests and the manner in which they were carried out at Boscombe Down rather made the ordinary commercial test pilot's mouth water. Normally, the commercial test pilots were rushed very badly in testing to ensure that the flying characteristics of their machines were satisfactory, in order that those machines might be hurried away to the Air Ministry testing establishments. They would all like to be given more time to do what Boscombe Down could do and to emulate the methods applied there.

The paper, he continued, emphasised quite clearly that instrumentation was coming more and more to the fore in the testing of aircraft. In that connection he was particularly interested in the development of the accurate measurement of the temperature of the air in which the machine was flying. Before any machine was tested, all concerned with it tried to predict the speed which it would attain. Many of the performance and cooling figures later submitted, however well intentioned, must be in error, because accurate measurements of the air temperature which materially affect both height and speed could not be obtained. Therefore, he hoped it would be possible for the aircraft companies to obtain some of the new thermometers for use in their own private tests, for the results would be of great value to them, in that the companies' figures would correspond more closely to the figures obtained by the Air Ministry Testing Establishments.

Again, he would like to see climbing tests conducted under conditions more closely approximating to operational conditions than Mr. Jones had indicated. In the paper it was stated that the testing establishment was prepared to carry out tests at increased climbing speeds where a closer cowling or smaller radiator would give higher performance with adequate cooling. Such tests were essential in order to ensure that the best performance was obtained without handicapping an aircraft by over-cooling.

In congratulating Mr. Jones upon the paper, he said it was comparable with the magnificent Wilbur Wright Memorial Lecture delivered recently by Dr. Warner. One could hardly convey a greater compliment to Mr. Jones than to say that he had proved a very close runner-up to Dr. Warner.

Mr. N. E. ROWE (*Fellow*): He had had the privilege of occupying some years ago the chair now occupied by Mr. Jones, and he was amazed by the advances which had since been made in flight testing methods. As recently as 1938 things were comparatively simple and straightforward. Mr. Jones had done a great work in putting forward a complete catalogue of the tests that were made and the manner in which they were made; that had not been done before so completely. As Group Captain Bulman had said, it would be of the greatest value to all concerned, and would undoubtedly prove to be a classic.

Emphasising Sir Frederick Handley Page's remarks concerning the organisation of test flying, Mr. Rowe said it had been his own experience that when the weather was good the aeroplane was bad, and when the aeroplane was good the weather was bad. Everything seemed then to get on extremely slowly. Therefore, he had always been inclined to ask why not conduct more of the tests on the ground rather than in the air? Surely the wind tunnel tests should make it possible to dispense with some of the full-scale testing. In that connection he asked whether the Americans were able to reduce their flight testing to any marked degree as compared with our own, bearing in mind all the instrumentation which had been effected in America and particularly the use of the full-scale tunnel there. One was impressed by the possibilities of using that tunnel as a means of reducing full-scale testing in the air.

For the future it was extremely important to push forward the development of aircraft quickly. The whole of the art was advancing at such a pace that they must avoid spending undue time in the process of obtaining vital information, though the final assessment could be made, of course, only in actual flight. Therefore, the organisation of test flying did require very careful thought. Sir Frederick Handley Page had stated the ideal when he had said that it should be possible for machines to leave the ground for their test flights at frequent intervals throughout the night and day, and had suggested that the machines should be fitted with calculators which would hand out the answers required within five minutes or so of landing. In dealing with that organisation they might consider whether they required a better correlation than they had yet achieved between the results obtained in the wind tunnel and in flight; or whether the tunnels should be used more systematically; and how far they could go in the testing of such things as engine cooling in full-scale wind tunnels. What must they look forward to in respect of test flying when they produced machines to fly at very high speeds and at very great heights?

Mr. C. C. A. WOODFORD (*Associate Fellow*): One of the reasons why the Americans were able to test their prototypes so quickly was that usually they built three at the same time. Further, the very intensive degree of instrumentation they had achieved—and which was still lacking in this country through lack of the equipment in quantity—had enabled them to obtain, in something like 8 or 10 or 12 hours of test flying, the amount of information which they could obtain here only after a few weeks or months of testing.

Group Captain BULMAN (*Fellow*): He would like to comment that, whatever his regard for the Americans, he would not admit that this country was second

to any in regard to testing methods or the time spent in conducting individual tests.

Mr. C. P. T. LIPSCOMB (*Fellow*): He expressed disappointment that no reference had been made in the paper to flying boats.

As the author was a late member of the staff of the M.A.E.E., Mr. Lipscomb expressed the hope that he did not subscribe to the wave of pessimism which was apparent in this country concerning the use of flying boats. One felt that some reference should be made to them in the paper as certain tests are peculiar to water borne aircraft.

All designers of marine aircraft require tests on the water performance, particularly to establish the upper and lower limits of stability under various conditions of all-up weight, speed, etc.

A great deal of information can be obtained from model tests carried out at R.A.E., but it requires correlation with full-scale results, as model tests cannot be relied upon with certainty.

Supporting Mr. Pierson's demand for a torque meter, Mr. Lipscomb urged that it was an essential item of test equipment and should be classified as of first priority. Not only was it necessary for test work but a great use could be found for it in the units. So many cases arose when an aircraft appeared to be badly down in performance, which were blamed by the constructor to the engine and by the engine builder to the aeroplane, that it needed a considerable amount of subsidiary testing to prove whether the trouble was due to the aircraft or the engine. It was, therefore, essential to know the power actually being developed by the engines.

With regard to electrical resistance strain gauges, Mr. Lipscomb said that they ought to consider, seriously, the development of the necessary technique for the use of these gauges in all test work because designers had so often, in the past, suffered from certain requirements being laid down for all aircraft, irrespective of type, as a result of a failure on a particular aeroplane.

The use of strain gauges would establish, in many cases, the need for universal application of such requirements.

Finally, he would like to see more use made of V.G.. recorders, not so much for test work as for use on production aeroplanes. These would considerably help in establishing the envelope conditions for each type of aircraft when laying down requirements for rationalised stressing. A certain amount of preliminary work has been done, but does not appear to have carried very far.

Flight Lieutenant P. G. LUCAS (*Associate Fellow*): He thought that modern flight testing, which demanded the application of a very comprehensive list of tests using specialised equipment, threw a very great responsibility on the test pilot. It was essential, therefore, for him to be backed up by an expert technical staff, and that they should work together in the closest possible manner.

Many pilots would like to take advantage of the use of wireless to enable them to carry out flight tests under overcast conditions, but in these circumstances the pilot's responsibility was increased even further, perhaps to a greater extent than was justifiable, when flying a valuable and possibly only prototype.

One of the main reasons for delays in getting through a development programme when only one prototype was available, and particularly in the case of a single-seater fighter, was the shortage of fuel and space for specialised equipment resulting generally in only one job being done at a time. There was therefore a very strong case for building several prototypes so that the work could be split up with the result that unserviceability on any one aircraft would not hold up the whole programme. Further, by having more than one aircraft several jobs could be done at the same time after a period of inactivity, due to bad weather.

A SPEAKER: He would like to see additional curves of operation from cruising to maximum speed in level flight and when losing height; in addition to the

straight speed/height curves, he would like to have acceleration curves from one speed and condition to another.

The PRESIDENT: He would like to pay his personal tribute to Mr. Jones for a magnificent paper, and said one could be quite certain that it would be the test pilot bible for some years to come. He agreed thoroughly with Mr. Lipscomb that there should be included in it some information concerning flying boats, where they differed from land machines.

Discussing the curves showing the difference in respect of control as the result of the change from fabric to metal construction, the President asked whether the difference had been tracked down to the torsional stability control or whether it was due merely to the difference in the shape of the surface. The difference appeared to be so marked that it must be attributed to something very serious.

Mr. S. SCOTT-HALL (*Associate Fellow*) (*communicated*): In spite of the title of the paper to which the author has strictly adhered, one would have liked to have heard Mr. Jones' views on some of the more general aspects of aircraft testing.

What are Mr. Jones' views on the place taken by A. and A.E.E. in the general scheme of the tests of a new type of aeroplane between construction and handing over to an operational squadron? What tests does he expect a firm to have made before handing a new aircraft over to the official test pilots?

In this connection the function of the A. and A.E.E. seems from this paper to be three-fold:—

(1) To ensure Service acceptability and compliance with specification.
(2) To provide data for the subsequent use of the aircraft by the Service.
(3) To provide data for designers.

Work under item (3) (unless confined strictly to information obtained incidentally under headings (1) and (2) would appear to be more properly the province of the contracting firms. Yet it appears from the "Developments of Structural Testing," that more and more work of this kind will be undertaken by A. and A.E.E., or is it the intention once a method has been well established to encourage designers to make such measurements for themselves?

The author mentions in the Introduction the difficulties in performance measurements due to local disturbances of the air arising from the passage of the aircraft itself. It seems surprising that there is no mention anywhere in the paper of difficulties due to up currents and general regional motion of the air in which performance tests are made. This was a source of trouble formerly. Has it been overcome?

On the question of comparative performance measurements on aeroplanes of the same type, does Mr. Jones think that variations of airframe dimensions within the allowed tolerances are likely to be a troublesome source of error in making comparisons of modifications? Para. 9.4 indicates initially that he does, but a few sentences later he only asks for measurement of engine power and more knowledge of the effect of surface finish to make such tests reliable.

The writer always experienced great difficulty in obtaining consistent readings on Partial Climbs on multi-engined aircraft with a "dead" engine, and came to the conclusion that the performance under such conditions was hypersensitive to trimmer settings. It seemed that the accuracy necessary in repeating trimmer positions could not be achieved. Is this a misapprehension? If not, it would appear important from the point of view of getting home an aircraft damaged in raids.

Lastly, is the time honoured law for variation of full throttle engine power (P varies as $p^{\frac{1}{2}}\sigma^{\frac{1}{2}}$) still regarded as valid?

REPLY TO THE DISCUSSION.

Mr. JONES said he would like to deal first with the President's question. He and his colleagues had not actually measured the difference between the form of the

elevator with fabric and with metal on it, so that they could not say whether the difference noted was due to torsion or to fabric deflection. But the R.A.E. had made tests on a Spitfire aileron, which had shown considerable fabric distortion when the aeroplane was rolled at high speed. He imagined, therefore, that the difference was due mainly to fabric deflection and not to distortion or twisting of the elevator.

In reply to Mr. Lipscombe, he said he did not like "this flying boat business." He did not wish to make any differentiation between the flying boat and the land plane, because when they were in the air they were in fact similar. If he were to differentiate he might say something which would tell against the flying boat, and he did not wish to do that; it should be able to do the same as the land plane when it was in the air.

Expressing agreement with Sir Frederick Handley Page that bad weather did deter activity in the testing of aircraft, he said it was not quite so much a deterrent nowadays as formerly, at any rate at Boscombe Down. There they tested aeroplanes above the cloud when the sky was overcast, provided the cloud bottom was not below about 800 ft.; they flew above 10/10ths overcast cloud, provided they were above 2,000 ft.

They did, of course, use navigational and wireless aids to a large extent on the big aeroplanes, when those aeroplanes were delivered to Boscombe Down with that equipment fitted. Often it was not fitted, and they spent some time fitting the equipment themselves. But a lot could be done above the clouds even without the aid of such equipment, provided the pilot had with him someone who could take a log of the direction of flight, the wind speed, etc., so that he could hope to land at the right place.

It was pleasing to hear the remarks of the various pilots who had taken part in the discussion. There was not much that he could reply to in connection with their contributions. He did appreciate that the test pilots of the aircraft firms had an enormous amount of development work to do before the aeroplanes were delivered to the A. and A.E.E. or other experimental establishments. At the same time, he did suggest that the aircraft firms could achieve some acceleration of their testing by adopting more set tests during the development flight period, and possibly by fitting in the large aeroplanes the equipment which Sir Frederick Handley Page had suggested should be fitted, so providing more facilities for navigation and for ensuring that the machines would get back to their bases without difficulty.

(*Communicated*): He had, in his spoken reply, misinterpreted Mr. Pierson's remarks when he pleaded for a propeller pitch lock to enable the change in engine power to be determined simultaneously with a change of mixture strength. At the time of the discussion he was under the impression that Mr. Pierson was suggesting a pitch lock to take the place of a torque dynamometer, but this was obviously not his intention. He agreed that a method for locking the propeller pitch during carburation and fuel consumption tests would be most valuable.

Both Sir Frederick Handley Page and Mr. N. E. Rowe commented on the loss of time in full-scale work due to unserviceability and bad weather, and Mr. Rowe suggested that more work should in consequence be made in large wind tunnels. This problem has faced them for many years and they always seem to be designing a full-scale tunnel, but by the time it was built it was either not large enough or its power was insufficient. If aircraft sizes persist in increasing, this state of affairs will presumably always exist, and it will therefore never be possible to make tests in a so-called full-scale tunnel. In addition, the preparation of aircraft for test in large tunnels takes a long time, and, in general, there is a large list of important jobs waiting for the one and only tunnel which can be used for the particular tests in mind. Thus, it was his experience that tests made in large wind tunnels do not necessarily get completed in less time than the

corresponding flight tests. He did not think they could afford to reduce the amount of flight test work, but he did think they could afford to eliminate some of the work which is now done in tunnels too small to produce reliable results. He would suggest that they required much more controlled flight test work and much more tunnel work made in tunnels of adequate size and power.

The operational data required by one speaker, such as acceleration in level flight from one speed to another corresponding to changes of power do not, in general, form part of the tests required to assess the performance and handling characteristics of a type, but he agreed that they should be measured since they are of value in deciding the tactical use of a fighter type.

The first series of Mr. Scott-Hall's questions is hardly relevant to the subject of the paper, but a statement on item (3) of this series is, however, not out of place. They should remember that the word " designers " should, in this case, be interpreted in its very widest sense. For example, full-scale data are not obtained solely for the guidance of the designer of the type, but primarily to assist in the technical development of aircraft in general. In addition, the various research establishments require accurate full-scale information on all types in order that they can augment their test methods as time proceeds, and to forecast more accurately the full-scale performance of subsequent types.

Performance tests made on the same aircraft to determine the effect of changes such as :—Air intake, exhaust layout, propellers, etc., require torquemeters, but the same tests spread over a number of aircraft cannot result in precise conclusions, even though torquemeters may be fitted, unless the surface finishes of the aircraft are identical.

In respect to the " difficulties in performance measurements due to up currents and general regional motion of the air," these still exist, but they are in general of less importance than formerly, except near the ceiling of the aircraft where the rate of climb and speed are low. Quantitatively, up currents make a smaller percentage effect at low and medium altitudes now that the performance is so much greater than it used to be. However, as stated in the paper at the end of para. 12, the rate of climb and ceiling are corrected for wind gradient.

The performance of multi-engined aircraft with one or more engines dead is, as stated in the paper, critical to atmospheric and engine power conditions. It is also dependent on the control deflections to give the mode of flight required, but whether the control is held by the pilot on the stick or rudder bar, or by the trimmers, is immaterial.

It is now generally accepted that the power of the modern I.C.E. installed in aircraft varies approximately as the density rather than $p^{\frac{1}{2}}\sigma^{\frac{1}{2}}$ as found formerly

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

DEAR SIR,

COMPARISON OF VARIOUS METHODS FOR DETERMINING FLIGHT SPEED AT GREAT ALTITUDES.

J. of the R.Ae.S., Jan., 1944. Translated from Luftwissen, Sept., 1942.
Written by R. Schmidt. Translated by L. J. Goodlet.

The three methods compared in this article are:—

1. Dornier air log.
2. Dynamic pressure.
3. Ground calibration by gyro-stabilized vertical sight telescopes.

The last method is used for calibration only, but may be used as a basis for comparison with the other two.

Schmidt correctly points out that dynamic pressure measurement has the following disadvantages:—

1. Interference of obstructions with static pressure.
2. Difficulty of calibration.
3. Effect of Mach number.
4. Air temperature errors.
5. Elastic pressure capsule errors due to hysteresis and temperature.
6. Inaccuracy of mean values.

He then claims to prove that the Dornier air log is more accurate than the dynamic pressure method and more accurate than the ground contact method (by which he calibrated the log). This after only four calibration runs! And these at low level and quite short (8 km.). The method by which he attempts to prove this is a masterpiece of confusion.

He first introduces the idea of the quadrangle of error without explaining its use. However, we must remember, even if Schmidt forgets, that the quadrangle of error is a measure of the consistency of the speed of the flight and has *nothing* to do with the instrument. Both the distance and the time are measured separately from the instrument and a small closure of the quadrangle of error is a good reflection on the pilot and not on the speed indicator. Yet it is on this basis that Schmidt proves the superiority of the Dornier instrument. His method of work is quite confused. He describes it as follows:—

> "The air log is towed on a 30 m. cable and its revolutions recorded by a counter on the aeroplane. At the same time, a stop-watch is intermittently operated, allowing the number of revolutions over given intervals of time to be counted. The instrument errors are exceedingly small; the rotor pitch is about 4.4 m., and at 130 m./sec. airspeed the turning speed of the rotor is about 30 rev. per sec. If the stop-watch timing accuracy is within 0.1 sec. the error in determining the distance flown will be $\Delta S = 30/10 \cdot 4.4 = 13$ metres, or a negligibly small variation of 0.00065 of the total measuring length of about 20,000 metres."

Now this stop-watch error is for each reading, and if the watch is "intermittently operated, allowing the number of revolutions over given intervals of time to be counted," then this error is not for the whole 20,000 metre course, but for

each stop-watch reading. Or, as is more likely, the stop-watch may not be operated over given intervals of time at all, but over the whole course. If this is so, why does he say the opposite?

Schmidt goes to great length to point out the fact that, as the log integrates the readings for a run, while a pressure device gives only discreet values that must be averaged and summed arithmetically, the log therefore is more accurate in calibration. He neglects to mention that if he wants to read velocity in the ship he will have to calibrate a gauge with discreet velocity readings against the speed of the rotor, a process which is hardly more accurate than photo-observed results followed by integration on a pressure device.

On page 12 Schmidt says: " Owing to the insignificant frictional losses, the air log is almost completely unaffected by differences in altitude." On page 18 he contradicts this and then follows with an alleged proof of his point (note the passages in italics):—

> " The effective pitch of the log rotor tends to increase with altitude, owing to the friction in the rotor bearings. The relative importance of the frictional effect will obviously vary inversely as the turning moment exerted by the airflow; which, however, is proportional to the air density, *i.e.*, at $\rho=0$ the rotator ceases to function, and the apparent pitch becomes infinitely great. If the ratios of log pitch at varying altitudes to log pitch at the ground (4.405) are plotted against the air density (Fig. 5), the log altitude correction factors are obtained; it must be remembered, however, that the log pitch is affected by the same errors as the airspeed. Plotting the ratio of altitude pitch/ground pitch against air density produces the curve shown in Fig. 5. The zone of scattering is composed of two sets of values—scattering of the individual values at altitude, and scattering of the reference ground value; obviously, therefore, *there is no relationship between altitude and range of scattering—the errors of airspeed measurement are therefore accidental and not related to the altitude.* On the other hand, the dependence of effective log pitch on altitude is unquestionable, and there is no reason to assume that *the relationship between effective log pitch and air density is other than steady.* Consequently, the fair curve for the log pitch must be drawn steadily and always within the range of scattering of the measured values; which leads *to the conclusion that the scattering of these values is almost exclusively due to errors inherent in the method of quadrilateral test flights, and not to any unsteadiness in the running of the log rotor, i.e., air log readings are still far more accurate than the results of measurements by means of quadrilateral calibration flights; unfortunately, no more accurate basis of comparison exists,*"

which, as far as this writer can see, is a complete " non-sequitor."

He next shows the " inaccuracies " of the dynamic pressure method by showing what is really the deviation from the mean, uncorrected, is greater for the dynamic pressure method, than the deviation from the mean (which may have actually really existed and is no indication of error), corrected by an arithmetical process, of the log.

The implications of this distorted presentation of data are, in this writer's opinion, unjustified. Somewhere may possibly be a proof of the validity of his method, but Schmidt has certainly not presented it and on the face of it the article seems to be a series of unproven claims.

To illustrate his method, Schmidt shows how the log worked for a series of tests of airspeed with the propeller having:—

(1) Polished blades on suction side.
(2) A coating of anti-glare varnish.
(3) Varnished and sanded—

a series in which extreme precision is needed. His results show 12 relatively consistent points; that is, yielding three distinct straight lines. This requires a consistency of approximately 2 m.p.h., which is about what he obtained. Again, we are talking about *consistency* in tests of this type, and experimental tests used for this purpose—and not of absolute accuracy. His results on this test are no proof of the accuracy of the instrument. Furthermore, a dynamic pressure indicator on a test of this type would match these results for *consistency*. Moreover, his errors apparently did not include the instantaneous readings so necessary to the pilot, but was the much more accurate method of taking the integrated log reading. The other disadvantages, such as inconvenience in flight manœuvres, descent and retraction, are not mentioned. All the transmitting difficulties, so necessary in flight, are overlooked in these runs, where the sum of revolutions could be used.

As far as this writer can see, the author's claims for the Dornier log have not been justified.

The possibility of substituting a log, or trailing bomb, for a pressure indicator, as far as experimental test work is concerned, has a certain amount of interest and validity. It may well prove fruitful to investigate this field either by experimentation or reference to other articles, but Schmidt's article is of no use whatsoever. His remarks on the functioning of the depressor vanes may at best be of limited value in the design of such logs.

Yours faithfully.

H. D. Block, Flight Engineer,
Goodyear Aircraft Co.

REVIEWS.

Introductory Magnetism and Electricity.

T. M. Yarwood. Macmillan and Co. 1944. 2/6.

A simply written textbook for the use of A.T.C. cadets and R.A.F. trainees, explaining the basic principles of magnetism and electricity. It is fully illustrated by diagrams and pictures, and contains a series of test questions on each chapter. More ground is covered than is usual in an elementary textbook, the chapter on the Morse circuit, telegraph, telephone and teleprinter being particularly practical and interesting.

The Recognition of Operational Aircraft.

Capt. G. B. Ransford. Sir Isaac Pitman and Sons. 1944. 3/6.

Captain Ransford's main idea is to get away from the silhouette—hitherto the recognised basis for all training in recognition of aircraft. His method reminds us of certain brands of shorthand, warranted to produce a high speed after six lessons. In brief: Learn your aircraft in groups, pick out some distinctive feature of each group (" British fighters have short noses "; " a peculiarity of German bombers—presumably to stiffen morale—is the tendency to house the crew all bunched together in the nose "), and then differentiate individual aeroplanes with a cheerful irreverence (" the Mitchell has large fins and rudders which appear to be in danger of falling off "). The method, if unorthodox, is at least amusing, and, taken in conjunction with the normal silhouette training, should give good results.

Teach Yourself Meteorology.

" Aeolus." Hodder and Stoughton, Ltd., for the English Universities Press, Ltd. 1944. 3/-.

As general reading, this book is more interesting than the average elementary textbook on Meteorology, for the author has escaped the hypnotic effect of the 2nd Class Navigator's syllabus and has touched on various physical phenomena that are intrinsically interesting and not merely potential winners of examination marks. We particularly enjoyed the chapters on Light and Sound Phenomena and on Submarine Weather—two aspects of the subject which have hitherto received little attention. By internal evidence, the author is a physicist rather than a navigator or an engineer.

The "SWORDFISH"
The Ocean Gladiator.
Widely distributed in the warm seas, and a mighty antagonist There exist records of great sport with swordfish in the Straits of Messina about 100 B.C
We have heard of their activities in this, and other areas, in more recent times.
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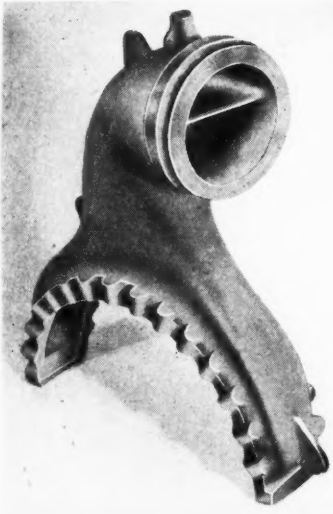

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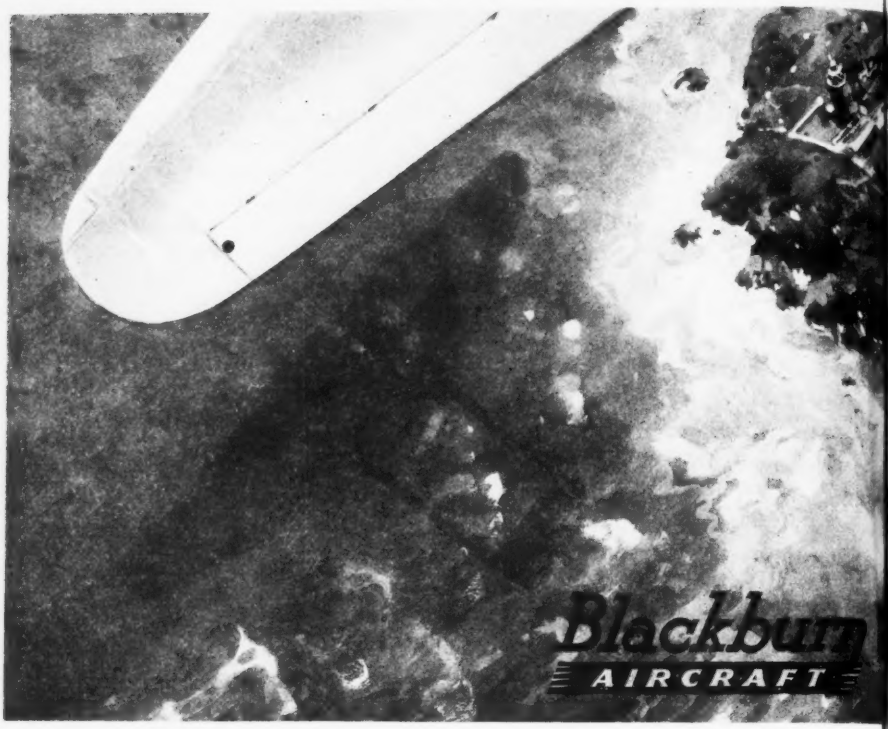

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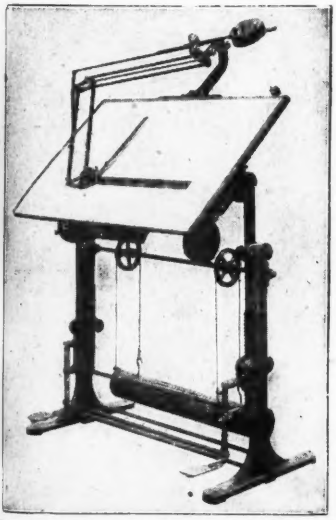

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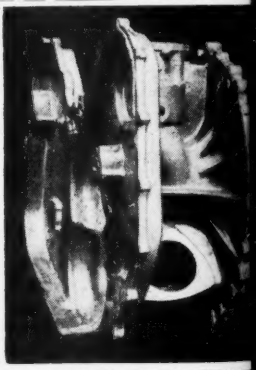

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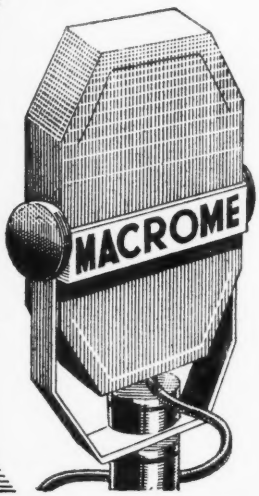

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